JC02 Rec'd PCT/PTO 0 8 MAR 2001

FORM PTO-1390 REV. 5-93 US DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE **TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371**		ATTORNEYS DOCKET NUMBER **P01,0032**
		U.S.APPLICATION NO. (if known, see 37 CFR 1.5) 09/786742
INTERNATIONAL APPLICATION NO. **PCT/DE99/02721**	INTERNATIONAL FILING DATE **01 September 1999**	PRIORITY DATE CLAIMED **08 September 1998**
TITLE OF INVENTION **LASER RADIATION SOURCE**		
APPLICANT(S) FOR DO/EO/US **Heinrich JÜRGENSEN**		

Applicant herewith submits to the United States /Designated/Elected Office (DO/EO/US) the following items and other information.

1. ■ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. □ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ■ This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay.
4. ■ A proper Demand for International Preliminary Examination will be made by the 19th month from the earliest claimed priority date.
5. ■ A copy of International Application as filed (35 U.S.C. 371(c)(2))
   a. ■ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. □ has been transmitted by the International Bureau.
   c. □ is not required, as the application was filed in the United States Receiving Office (RO/US)
6. ■ A translation of the International Application into English (35 U.S.C. 371(c)(2).
7. ■ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. §371(c)(3))
   a. □ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. □ have been transmitted by the International Bureau.
   c. □ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ■have not been made and will not be made.
8. □ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ■ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)). **Unexecuted**
10. □ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. ■ An Information Disclosure Statement under 37 C.F.R. 1.97 and 1.98; **(PTO 1449, Prior Art, Search Report)**.
12. □ An assignment document for recording. A separate cover sheet in compliance with 37 C.F.R. 3.28 and 3.31 is included **(SEE ATTACHED ENVELOPE)**
13. ■ A FIRST preliminary amendment.
    □ A SECOND or SUBSEQUENT preliminary amendment.
14. ■ A substitute specification **- Marked up copy of Substitute Specification.**
15. □ A change of power of attorney and/or address letter.
16. ■ Other items or information:
    a. ■ Submission of Drawings **- Thirty Nine sheets of Drawings - Drawing Correction Letter - Translation of drawings**
    b. ■ **EXPRESS MAIL #EL655301655US dated March 8, 2001.**

JC02 Rec'd PCT/PTO 08 MAR 2001

U.S. APPLICATION NO. (if known, see 37 C.F.R. 1.5)	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER
09/786742	PCT/DE99/02721	P01,0032

BASIC NATIONAL FEE (37 C.F.R. 1.492(a)(1)-(5):

Search Report has been prepared by the EPO or JPO $860.00

International preliminary examination fee paid to USPTO (37 C.F.R. 1.482) $690.00

No international preliminary examination fee paid to USPTO (37 C.F.R. 1.482) but international search fee paid to USPTO (37 C.F.R. 1.445(a)(2) $760.00

Neither international preliminary examination fee (37 C.F.R. 1.482) nor international search fee (37 C.F.R. 1.445(a)(2) paid to USPTO $970.00

International preliminary examination fee paid to USPTO (37 C.F.R. 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) .... $ 96.00

ENTER APPROPRIATE BASIC FEE AMOUNT =				$860.00	
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 C.F.R. 1.492(e)).				$ 0	
Claims	Number Filed	Number Extra	Rate		
Total Claims	73 - 20 =	53	X $ 18.00	$ 954.00	
Independent Claims	4 - 3 =	1	X $ 80.00	$ 80.00	
Multiple Dependent Claims			$270.00 +	$	
TOTAL OF ABOVE CALCULATIONS =				$ 1894.00	
Reduction by 1/2 for filing by small entity, if applicable. Verified Small Entity statement must also be filed. (Note 37 C.F.R. 1.9, 1.27, 1.28)				$	
SUBTOTAL =				$860.00	
Processing fee of $130.00 for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$	
TOTAL NATIONAL FEE =				$860.00	
Fee for recording the enclosed assignment (37 C.F.R. 1.21(h). The assignment must be accompanied by an appropriate cover sheet (37 C.F.R. 3.28, 3.31). $40.00 per property +					
TOTAL FEES ENCLOSED =				$1894.00 $[redacted]	
				Amount to be refunded	$
				charged	$

a. ■ A check in the amount of $**1894.00** to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. __________ in the amount of $ _______ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ■ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. **501519**. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 C.F.R. 1.494 or 1.495 has not been met, a petition to revive (37 C.F.R. 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

Schiff Hardin & Waite
Patent Department
6600 Sears Tower
Chicago, Illinois 60606
CUSTOMER NO. 26574

Brett A. Valiquet
SIGNATURE

Brett A. Valiquet
NAME

27,841
Registration Number

BOX PCT

IN THE UNITED STATES ELECTED OFFICE
OF THE UNITED STATES PATENT AND TRADEMARK OFFICE
UNDER THE PATENT COOPERATION TREATY-CHAPTER II

PRELIMINARY AMENDMENT

APPLICANT: HEINRICH JÜRGENSEN

DOCKET NO: P01,0032

SERIAL NO:

GROUP ART UNIT:

EXAMINER:

INTERNATIONAL APPLICATION NO: PCT/DE99/02721
INTERNATIONAL FILING DATE: 01 September 1999
INVENTION: **"LASER RADIATION SOURCE"**

Assistant Commissioner for Patents,
Washington, D.C. 20231

Sir:

As a Preliminary Amendment for entry into the National Stage for the above-identified PCT application, the following is submitted:

IN THE DRAWINGS:

Please amend the drawings as indicated in the attached Drawing Correction Letter.

IN THE SPECIFICATION:

Please enter the enclosed Substitute Specification and Abstract. No new matter is being entered in the

Substitute Specification. Also enclosed is a marked up version of the substitute specification showing the changes.

IN THE CLAIMS:

On page 100 of the claims, delete "Patent Claims" and substitute --**I CLAIM AS MY INVENTION**--.

Please cancel claims 1-263 without prejudice.

Please substitute claims 264-336 as follows:

264. A laser radiation source for generating a laser beam with high power density and high energy for processing material, comprising:

a plurality of directly modulatable, diode-pumped fiber lasers having outputs arranged in a first ordering pattern; and

an optical unit connected to the outputs of the fiber lasers wherein laser beams emerging from the outputs of the individual fiber lasers are shaped and aligned such that they impinge onto a processing surface in a second ordering pattern.

265. The laser radiation source according to claim 264 wherein the outputs of the fiber lasers are arranged in at least one of at least one track next to one another and in at least one plane above one another for forming the first ordering pattern.

266. The laser radiation source according to claim 264 wherein the outputs of the fiber lasers are arranged in a bundle for forming the first ordering pattern.

267. The laser radiation source according to claim 264 wherein the laser beams are combined and bundled in the optical unit for forming the second ordering pattern such that the laser beams generate processing points on the processing surface lying next to one another at at least one of in at least one track and lying above one another in at least one plane.

268. The Laser radiation source according to claim 264 wherein the laser beams are combined and bundled in the optical unit for forming the second ordering pattern such that the laser beams generate a single processing point on the processing surface.

269. The laser radiation source according to claim 264 wherein the laser beams generated in the fiber lasers are directly modulated.

270. The laser radiation source according to claim 264 wherein at least one modulation device is provided in the optical unit for modulation of the laser beams.

271. The laser radiation source according to claim 270 wherein the modulation device is designed as one of an electro-optical modulator and an electro-optical deflector.

272. The laser radiation source according to claim 270 wherein the modulation device is designed as one of

an acousto-optical modulator and an acousto-optical deflector.

273. The laser radiation source according to claim 270 wherein the modulation device is designed multi-channel.

274. The laser radiation source according to claim 264 wherein

the outputs of the fiber lasers are coupled to the optical unit with adjustable terminators; and

the terminators comprise lenses for shaping the laser beams.

275. The laser radiation source according to claim 274 wherein

the optical unit comprises a radiation entry and a beam exit; and

mounts are provided at the radiation entry, the terminators being adjustable in said mounts such that the laser beams at the beam exit of the optical unit are directed onto the processing surface.

276. The laser radiation source according to claim 264 wherein the output of at least one fiber laser comprises at least one passive fiber.

277. The laser radiation source according to claim 264 wherein

the optical unit comprises a radiation entry and a radiation exit; and

the optical unit comprising an optical unit in a region between the radiation entry and the radiation exit for merging the laser beams.

278. The laser radiation source according to claim 277 wherein at least one of mirrors, lenses, wavelength-dependent elements and polarization-dependent elements are employed for merging the laser beams.

279. The laser radiation source according to claim 277 wherein the optical unit for merging the laser beams are arranged at one of in front of and behind the modulation device.

280. The laser radiation source according to claim 264 wherein the optical unit comprises a unit for reducing spacing of symmetry axes of the laser beams.

281. The laser radiation source according to claim 264 wherein the optical unit comprises an optical transmission unit for optical transmission of the laser beams onto the processing surface.

282. The laser radiation source according to claim 281 wherein the optical transmission unit contains an interchangeable objective.

283. The laser radiation source according to claim 264 wherein the optical unit is designed such that the laser beams form beam constrictions in a region of the processing surface.

284. The laser radiation source according to claim 264 wherein the optical unit comprises an adjustable objective with long focal length with which focusing of processing points onto the processing surface is variable.

285. The laser radiation source according to claim 264 wherein the optical unit comprises an adjustable vario objective with which focusing of processing points onto the processing surface and a spacing between the processing points is variable.

286. The laser radiation source according to claim 264 wherein the laser radiation source comprises a unit with which unwanted laser beams that are not intended to produce a processing effect on the processing surface are rendered ineffective.

287. The laser radiation source according to claim 286 wherein the laser radiation source comprises an intercept arrangement with which unwanted laser beams that are not intended to produce a processing effect on the processing surface are kept away from the processing surface.

288. The laser radiation source according to claim 287 wherein the intercept arrangement comprises a sump into which unwanted laser beams that are not intended to produce a processing effect on the processing surface are conducted.

289. The laser radiation source according to claim 288 wherein the sump comprises an absorbent material.

290. The laser radiation source according to claim 288 wherein the sump is designed as a heat exchanger.

291. The laser radiation source according to claim 287 wherein the unwanted laser beams are conducted onto the intercept arrangement with mirrors.

292. The laser radiation source according to claim 291 wherein an optical element that retains laser radiation potentially reflected or back-scattered from the intercept arrangement is inserted between the mirrors and the intercept arrangement.

293. The laser radiation source according to claim 264 wherein the laser radiation source comprises a unit for defocussing unwanted laser beams with which the unwanted laser beams that are not intended to produce any processing effect on the processing surface are defocussed such that they produce no processing effect on the processing surface.

294. The laser radiation source according to claim 264 wherein at least one of the optical unit and parts thereof comprise a unit that prevents a contamination of the optical components.

295. The laser radiation source according to claim 294 wherein at least one the optical units and parts thereof are free of materials that give off gasses.

296. The laser radiation source according to claim 294 wherein at least one of the optical unit and parts thereof are closed gas-tight.

297. The laser radiation source according to claim 294 wherein at least one of the optical unit and parts thereof comprises optical windows for passage of the laser beams.

298. The laser radiation source according to claim 264 wherein the outputs of the fiber lasers are combined in a receptacle in the optical unit, said receptacle being designed such that the laser beams are directed onto the processing surface.

299. The laser radiation source according to claim 298 wherein the receptacle is designed multi-part.

300. The laser radiation source according to claim 299 wherein a first part of the receptacle contains the

unit for merging the laser beams and a subsequent, second part contains a transmission unit.

301. The laser radiation source according to claim 300 wherein the first part of the receptacle is designed as a housing.

302. The laser radiation source according to claim 301 wherein the housing is evacuated.

303. The laser radiation source according to claim 301 wherein the housing is filled with a protective atmosphere.

304. The laser radiation source according to claim 264 wherein an arrangement for removal of material eroded from the processing surface is provided between the optical unit and the processing surface.

305. The laser radiation source according to claim 304 wherein

the arrangement for removal of the material eroded from the processing surface comprises a through opening with a beam entry and a beam exit for the laser beams directed onto the processing surface, whereby a processing space is formed between the beam exit and processing surface;

at least one extraction channel connected to the processing space is provided; and

the extraction channel is in communication with a vacuum generating unit.

306. The laser radiation source according to claim 305 wherein a through opening is conically designed between beam entry and beam exit.

307. The laser radiation source according to claim 304 wherein the arrangement comprises at least one compressed air channel whose one opening is connected to the processing space and whose other opening is connected to a generating device for at least one of compressed air and gas.

308. The laser radiation source according to claim 307 wherein

the compressed air channel is designed as a nozzle bore; and

the axis of the nozzle bore is directed onto the processing spot.

309. The laser radiation source according to claim 304 wherein the arrangement comprises at least one bypass bore connected to the compressed air generating device.

310. The laser radiation source according to claim 309 wherein the bypass bore is arranged such that an air flow in the direction of the processing surface arises in a through opening.

311. The Laser radiation source according to claim 304 wherein a filter device for picking up the material released during the processing of material is provided between the extraction channel and the vacuum generating device.

312. The laser radiation source according to claim 264 wherein a control circuit for regulating the laser radiation is provided.

313. The laser radiation source according to claim 264 wherein continuous wave lasers are provided for generating the laser beams, said continuous wave lasers being respectively capable of being modulated with a modulator arranged outside the laser resonator, with at least one of the pump energy and directly.

314. The laser radiation source according to claim 264 wherein quality-switched lasers known as Q switch lasers are provided for generating the laser beams, said quality-switched lasers being respectively capable of being modulated with at least one of a modulator arranged outside the laser resonator, with the pump energy, with the Q-switch and directly.

315. The laser radiation source according to claim 264 wherein the laser radiation source is employed in an apparatus for processing material, particularly in an apparatus for producing printing forms.

316. An apparatus for processing material with laser radiation having high power density and high energy, comprising:

at least one laser radiation source displaceable relative to a processing surface for generating a laser beam and that comprises a number of directly modulatable, diode-pumped fiber lasers whose outputs are arranged in a first ordering pattern, comprising an optical unit connected to the outputs of the fiber lasers, and wherein the laser beams emerging from the outputs of the individual fiber lasers are shaped and directed such that they impinge a processing surface in a second ordering pattern;

a cooling system for cooling the laser radiation source;

a material carrier for the processing surface;

a drive unit for moving the material carrier with the processing surface in a principal processing direction and for relative movement of the material carrier with the processing surface relative to the laser radiation source in a secondary processing direction; and

a control unit for controlling the laser radiation source and the drive unit.

317. The apparatus for processing material according to claim 316 wherein the outputs of the fiber lasers in the laser radiation source are arranged in at least one of at least one track next to one another and

in at least one plane above one another for forming the first ordering pattern.

318. The apparatus for processing material according to claim 316 wherein the outputs of the fiber lasers in the laser radiation source are arranged in a bundle for forming the first ordering pattern.

319. The apparatus for processing material according to clam 316 wherein the laser beams are combined and bundled in the optical unit of the laser radiation source for forming the second ordering pattern such that the laser beams generate processing points on the processing surface lying next to one another in at least one of at least one track and lying above one another in at least one plane.

320. The apparatus for processing material according to claim 316 wherein the laser beams are combined and bundled in the optical unit of the laser radiation source for forming the second ordering pattern such that the laser beams generate a single processing point on the processing surface.

321. The apparatus for processing material according to claim 316 wherein an arrangement for removal of the material eroded from the processing surface is provided.

322. The apparatus for processing material according to claim 321 wherein the arrangement for removal of the material eroded from the processing surface is designed as one of a scraper and a brush device.

323. The apparatus for processing material according to claim 316 wherein at least some components of the apparatus are accommodated in a housing.

324. The apparatus for processing material according to claim 316 wherein

the material carrier is a drum that rotates in the principal processing direction; and

the laser radiation source is displaced axially at the drum in the secondary processing direction with a carriage.

325. The apparatus for processing material according to claim 316 wherein

the material carrier is a flat bed;

the laser radiation source comprises a light deflector that deflects the laser beams across the flat bed in the principal processing direction; and

the flat bed and at least the light deflector are displaceable relative to one another in the secondary processing direction with a linear guide.

326. The apparatus for processing material according to claim 316 wherein

the material carrier is a hollow bed;

the laser radiation source comprises a light deflector that deflects the laser beams across the hollow bed in the principal processing direction; and

the hollow bed and at least the light deflector are displaceable in the secondary processing direction with a linear guide.

327. The apparatus for processing material according to claim 316 wherein the apparatus is designed for the production of printing forms and the material to be processed is a printing cylinder and a printing plate.

328. The apparatus for processing material according to claim 316 wherein the laser radiation source comprises at least one modulation device provided in the optical unit for modulation of the laser beams and wherein the modulation device is designed as one of an electro-optical modulator, an electro-optical deflector, an acousto-optical modulator, and an acousto-optical deflector.

329. A method for generating a laser beam with high power density and high energy for processing material, comprising the steps of:

providing a laser radiation source formed of a plurality of modulatable, diode-pumped fiber lasers;

arranging outputs of the fiber lasers in a first ordering pattern;

providing an optical unit connected to the outputs of the fiber lasers; and

using the optical unit for shaping and aligning laser beams emerging from the outputs of the individual fiber lasers such that they impinge onto a processing surface in a second ordering pattern.

330. The method of claim 329 including the step of arranging the outputs of the fiber lasers in at least one of at least one track next to one another and in at least one plane above one another for forming the first ordering pattern.

331. The method of claim 329 including the step of arranging the outputs of the fiber lasers in a bundle for forming the first ordering pattern.

332. The method according to claim 329 including the further steps of combining and bundling the laser beams in the optical unit for forming the second ordering pattern such that the laser beams generate processing points on the processing surface lying next to one another at at least one of in at least one track and lying above one another in at least one plane.

333. The method according to claim 329 including the step of combining and bundling the laser beams in the optical unit for forming the second ordering pattern such that the laser beams generate a single processing point on the processing surface.

334. The method according to claim 329 including the step of directly modulating the laser beams generated in the fiber lasers with at least one of an electro-optical modulator, an electro-optical deflector, an acousto-optical modulator, and an acousto-optical deflector.

335. The method according to claim 329 including the step of coupling the outputs of the fiber lasers to the optical unit with adjustable terminators, and providing the terminators with lenses and using the lenses to shape the laser beams.

336. A laser radiation source for generating a laser beam with high power density and high energy for processing material, comprising:

a plurality of modulatable, diode-pumped fiber lasers having outputs arranged in a first ordering pattern; and

an optical unit coupled to the outputs of the fiber lasers wherein laser beams emerging from the outputs of the individual fiber lasers are shaped and aligned such that they impinge onto a processing surface in a second ordering pattern.

REMARKS

The specification, abstract, and drawings have been amended in accordance with U. S. format.

New claims are presented drawn in accordance with U. S. practice. These claims are not narrower than the

original claims and were not submitted for patentability reasons. Rather, they consolidate the PCT prosecuted patent claims and they are presented in a format based on U. S. practice. Method claims have also been added somewhat similar to the apparatus claims.

An Information Disclosure Statement is enclosed.

Respectfully submitted,

(Reg.No. 27,841)

Brett A. Valiquet
Schiff Hardin & Waite
Patent Department
6600 Sears Tower
Chicago, Illinois 60606
(312) 258-5786
Attorneys for Applicants
CUSTOMER NO. 26574

Rec'd PCT/PTO 14 SEP 2001

BOX PCT

IN THE UNITED STATES DESIGNATED OFFICE
OF THE UNITED STATES PATENT AND TRADEMARK OFFICE
UNDER THE PATENT COOPERATION TREATY-CHAPTER II

SUBMITTAL OF EXECUTED DECLARATION,
DRAWINGS, AND SECOND PRELIMINARY AMENDMENT

APPLICANT(S):	Jürgensen, Heinrich	**GROUP ART UNIT:**	
SERIAL NO.:	09/786,742	**EXAMINER:**	
FILED:	March 8, 2001		
TITLE:	**"LASER RADIATION SOURCE"**		

Hon. Assistant Commissioner for Patents,
Washington, D.C. 20231

SIR:

As a Second Preliminary Amendment for entry into the national stage of the above-identified PCT application, the following is submitted:

IN THE SPECIFICATION

Please enter the enclosed Second Substitute Specification and Abstract. No new matter is being entered in the Second Substitute Specification. Also enclosed is a marked-up version of the Second Substitute Specification showing the changes with respect to the First Substitute Specification.

IN THE CLAIMS

Please cancel claims 264-336.

Please substitute claims 337-407 as follows:

337. A laser radiation source for generating laser beams with high power density and high energy for processing material, comprising:

at least one diode-pumped fiber laser;

each fiber laser comprising at least one output;

at least two of said outputs being arranged in a first ordering pattern; and

the laser beams emerging from the outputs of the individual fiber lasers being at least one of shaped and aligned such that they impinge onto a processing surface in a second ordering pattern.

338. The laser radiation source according to claim 337 wherein the outputs of the fiber lasers are arranged in at least one of at least one track next to one another and in at least one plane above one another for forming the first ordering pattern.

339. The laser radiation source according to claim 337 wherein the outputs of the fiber lasers are arranged in a bundle for forming the first ordering pattern.

340. The laser radiation source according to claim 337 wherein the laser beams are combined and bundled for forming the second ordering pattern such that the laser beams generate processing points on the processing surface lying next to one another in at least one of at least one track and lying above one another in at least one plane.

341. The laser radiation source according to claims 337 wherein the laser beams are combined and bundled for forming the second ordering pattern such that the laser beams generate a single processing point on the processing surface.

342. The laser radiation source according to claim 337 wherein for at least one of shaping and aligning the laser beams, the outputs of the fiber lasers are correspondingly at least one of aligned and optically processed.

343. The laser radiation source according to claim 337 wherein at least one optical unit is connected to the outputs of the fiber lasers at least one of for the shaping and the alignment of the laser beams.

344. The laser radiation source according to claim 337 wherein the laser beams generated in the fiber lasers are directly modulated.

345. The laser radiation source according to claim 343 wherein at least one modulation device is provided in the optical unit for the modulation of the

laser beams.

346. The laser radiation source according to claim 345 wherein the modulation device is designed as at least one of a single-channel electro-optical modulator, a multi-channel electro-optical modulator and an electro-optical deflector.

347. The laser radiation source according to claim 345 wherein the modulation device is designed as at least one of a single-channel acousto-optical modulator, a multi-channel acousto-optical modulator and an acousto-optical deflector.

348. The laser radiation source according to claim 345 wherein the laser beams entering into the modulation device are split into at least two sub-beams that generate the processing points on the processing surface.

349. The laser radiation source according to claim 343 wherein:

the outputs of the fiber lasers are coupled to the optical unit with terminators; and

the terminators comprise lenses for shaping the laser beams into beam bundles.

350. The laser radiation source according to claim 349 wherein:

the optical unit comprises a radiation entry and a radiation exit; and

mounts are provided at the radiation entry, the terminators being accepted in said mounts such that the beam bundles at the radiation exit of the optical unit are directed onto the processing surface.

351. The laser radiation source according to claim 349 wherein the terminators are adjustable in the mounts.

352. The laser radiation source according to claim 337 wherein the output of at least one fiber laser comprises at least one passive fiber.

353. The laser radiation source according to claim 343 wherein:

the optical unit comprises a radiation entry and a radiation exit; and

the optical unit comprises an optical unit in the region between radiation entry and radiation exit for merging the laser beams.

354. The laser radiation source according to claim 353 wherein the optical unit for merging the laser beams are arranged in the beam path at one of in front of and behind the modulation device.

355. The laser radiation source according to claim 343 wherein the optical unit comprises a unit for reducing a spacing of symmetry axes of the laser beams.

356. The laser radiation source according to claim 343 wherein the optical unit comprises a transmission unit for optical transmission of the laser beams onto the processing surface.

357. The laser radiation source according to claim 356 wherein the optical transmission unit contains an interchangeable objective.

358. The laser radiation source according to claim 343 wherein the optical unit is designed so that the laser beams form beam constrictions in a region of the processing surface.

359. The laser radiation source according to claim 343 wherein the optical unit comprises an adjustable lens with a long focal length compared to an objective with which focusing of the processing points onto the processing surface is variable.

360. The laser radiation source according to claim 343 wherein the optical unit comprises an adjustable vario objective with which at least one of the focusing of the processing points onto the processing surface and the spacing between the processing points is variable.

361. The laser radiation source according to claim 337 wherein the laser radiation source comprises a unit with which unwanted laser radiation that should not produce a processing effect on the processing surface are rendered ineffective.

362. The laser radiation source according to claim 361 wherein the laser radiation source comprises an intercept arrangement with which unwanted laser radiation is kept away from the processing surface.

363. The laser radiation source according to claim 362 wherein the

intercept arrangement comprises a sump into which the unwanted laser radiation is conducted.

364. The laser radiation source according to claim 363 wherein the sump comprises a material that absorbs the unwanted laser radiation.

365. The laser radiation source according to claim 363 wherein the sump is designed as a heat exchanger.

366. The laser radiation source according to claim 361 wherein the unwanted laser radiation is conducted into a sump with at least one mirror.

367. The laser radiation source according to claim 366 wherein an optical element that retains laser radiation at least one of reflected and back-scattered from the sump is inserted between the mirror and the sump.

368. The laser radiation source according to claim 361 wherein the laser radiation source comprises a system with which the unwanted laser radiation is spread over an adequately large region of the processing surface such that it produces no processing effect on the processing surface.

369. The laser radiation source according to claim 343 wherein at least one of the optical unit and parts thereof comprise a system that prevents a contamination of the optical components.

370. The laser radiation source according to claim 369 wherein at least one of the optical unit and parts thereof are free of materials that give off gasses.

371. The laser radiation source according to claim 369 wherein at least one of the optical unit and parts thereof are closed gas-tight and comprises optical windows for passage of the laser beams.

372. The laser radiation source according to claim 369 wherein at least one of the optical unit and parts thereof are evacuated.

373. The laser radiation source according to claim 369 wherein at least one of the optical unit and parts thereof are at least one of filled with a protective atmosphere and have protective atmosphere flowing therethrough.

374. The laser radiation source according to claim 343 wherein an arrangement for removal of the material eroded from the processing surface is

provided between the optical unit and the processing surface.

375. The laser radiation source according to claim 374 wherein:

the arrangement for removal of the material eroded from the processing surface comprises a through opening with a beam entry and a beam exit for the laser beams directed onto the processing surface, whereby a processing space is formed between beam exit and processing surface;

at least one extraction channel connected to the processing space is provided; and

the extraction channel is in communication with a vacuum generating unit.

376. The laser radiation source according to claim 375 wherein the through opening between beam entry and the processing space is designed constricted toward the beam exit.

377. The laser radiation source according to claim 374 wherein the arrangement comprises at least one compressed air channel whose one opening is connected to a processing space and whose other opening is connected to a generating device for at least one of compressed air and gas.

378. The laser radiation source according to claim 377 wherein:

the compressed air channel is designed as a nozzle bore; and

an axis of the nozzle bore is directed onto the processing points.

379. The laser radiation source according to claim 377 wherein the arrangement comprises at least one bypass bore connected to the compressed air generating device.

380. The laser radiation source according to claim 379 wherein the bypass bore is arranged such that an air flow in the direction of the processing surface arises in the through opening.

381. The laser radiation source according to claim 375 wherein a filter device for picking up the material released during the processing of material is provided between the extraction channel and the vacuum generating device.

382. The laser radiation source according to claim 337 wherein at least one control circuit for regulating the laser beams is provided.

383. The laser radiation source according to claim 337 wherein continuous wave lasers are provided for generating the laser beams, said continuous wave lasers being respectively capable of being modulated with a modulator arranged outside the laser resonator, with at least one of the pump energy and directly.

384. The laser radiation source according to claim 337 wherein quality-switched lasers are provided for generating the laser beams, said quality-switched lasers being respectively capable of being modulated with at least one of a modulator arranged outside the laser resonator, with pump energy, with a Q-switch and directly.

385. The laser radiation source according to claim 337 wherein the laser radiation source is employed in an apparatus for processing material, specifically in an apparatus for producing printing forms.

386. An apparatus for processing material with laser radiation having high power density and high energy, comprising:

at least one laser radiation source for generating laser beams for processing at least one processing surface;

the laser radiation source comprising at least one diode-pumped fiber laser;

each fiber laser comprising at least one output;

at least two of said outputs being provided;

the outputs of the fiber lasers being arranged in a first ordering pattern;

the laser beams emerging from the outputs of the individual fiber lasers being at least one of shaped and directed such that they impinge a processing surface in a second ordering pattern;

a cooling system for cooling the laser radiation source;

a controller for controlling the laser radiation source;

at least one material carrier for the processing surface; and

a unit for generating at least one relative movement between laser beams and the processing surface.

387. The apparatus for processing material according to claim 386 wherein the outputs of the fiber lasers are arranged in at least one of at least one track next to one another and in at least one plane above one another for forming the first ordering pattern.

388. The apparatus for processing material according to claim 386 wherein the outputs of the fiber lasers are arranged in a bundle for forming the first ordering pattern.

389. The apparatus for processing material according to claim 386 wherein the laser beams are combined and bundled for forming the second ordering pattern such that the laser beams generate processing points on the processing surface lying next to one another in one of at least one track and lying above one another in at least one plane.

390. The apparatus for processing material according to claim 386 wherein the laser beams are combined and bundled for forming the second ordering pattern such that the laser beams generate a single processing point on the processing surface.

391. The apparatus for processing material according to claim 389 wherein for at least one of shaping and alignment of the laser beams, the outputs of the fiber lasers are correspondingly at least one of aligned and optically processed.

392. The apparatus for processing material according to claim 386 wherein for at least one of shaping and alignment of the laser beams, at least one optical unit is connected to the outputs of the fiber lasers.

393. The apparatus for processing material according to claim 386 wherein the laser beams generated in the fiber lasers are directly modulated.

394. The apparatus for processing material according to claim 392 wherein at least one modulation device is provided in the optical unit for modulation of the laser beams.

395. The apparatus for processing material according to claim 386 wherein a cooling system is provided for cooling the laser radiation source.

396. The apparatus for processing material according to claim 386 wherein an arrangement for removal of the material eroded from the processing surface is provided.

397. The apparatus for processing material according to claim 396 wherein at least one of a scraper and a brush device for respectively scraping and brushing off the eroded material arising in the processing of material is provided.

398. The apparatus for processing material according to claim 386 wherein at least some components of the apparatus are accommodated in a housing.

399. The apparatus for processing material according to claim 386 wherein the material carrier is designed as a drum.

400. The apparatus for processing material according to claim 386 wherein the material carrier is designed as a flat bed.

401. The apparatus for processing material according to claim 386 wherein the material carrier is designed as a hollow bed.

402. The apparatus for processing material according to claim 386 wherein the apparatus is designed for production of printing forms and the material to be processed is at least one of a printing cylinder and a printing plate.

403. A method for generating laser beams with high-power density and high energy, comprising the steps of:

providing at least one diode-pumped fiber laser;

providing each fiber laser with at least one output;

arranging in a first ordering pattern at least two of said outputs; and

at least one of shaping and aligning the laser beams emerging from the outputs of the individual fiber lasers such that they impinge onto a processing surface in a second ordering pattern.

404. The method according to claim 403, including the step of providing at least one optical unit connected to the output of the fiber lasers for at least one of the shaping and the alignment of the laser beams.

405. The method according to claim 403, including the step of directly modulating the laser beams generated in the fiber lasers.

406. The method according to claim 403, including the step of utilizing the generated laser beams having high-power density and high energy for processing material.

407. The method according to claim 403 wherein the generated laser beams form a laser radiation source, and including the steps of cooling the laser radiation source with a cooling system, controlling the laser radiation source with a controller, utilizing the laser radiation source for processing material, providing at least one material carrier for the processing surface, and generating at least one relative movement between laser beams and the processing surface.

REMARKS

Enclosed is a Notice of Missing Parts. Responsive to that Notice of Missing Parts, please find enclosed the executed Declaration.

Please also find enclosed formal drawings incorporating all of the drawing corrections indicated in the first preliminary amendment.

After further review of the original Substitute Specification by the inventor, the inventor desired that certain improved translations be made throughout the Specification. Therefore a new, Second Substitute Specification is enclosed together with the marked-up copy showing changes made with respect to the first Substitute Specification. Changes also made at page 13 adding a date to the prior art reference and further explanation was provided at page 71. This addition is fully supported by the context of the Specification.

After reviewing the claims submitted in the first Substitute Specification, the inventor requested that the claims be broadened somewhat and this has been done in the newly presented claims.

A Supplemental Information Disclosure Statement is also enclosed.

Respectfully submitted by,

Brett Valiquet (Reg. No. 27,841)
Schiff, Hardin & Waite
Patent Department
6600 Sears Tower
233 South Wacker Drive
Chicago, Illinois 60606
Telephone: 312-258-5786
CUSTOMER NO. 26574
ATTORNEY FOR APPLICANT

I hereby certify that this correspondence is being deposited with the United States Postal Service as ~~First Class~~ EXPRESS Mail in an envelope addressed to: Assistant Commissioner for Patents, Washington, D. C. 20231 on September 14, 2001.

Brett A. Valiquet
Name of Applicants' Attorney

Signature

September 14, 2001
Date

2:500770.1

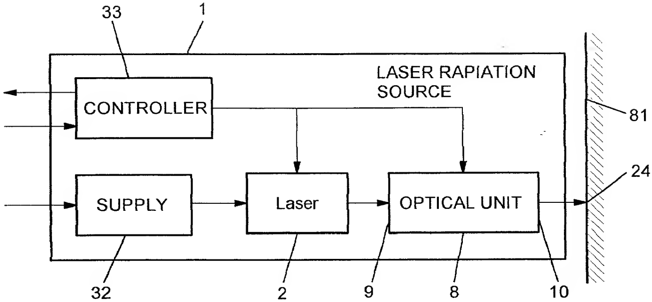


Fig. 1

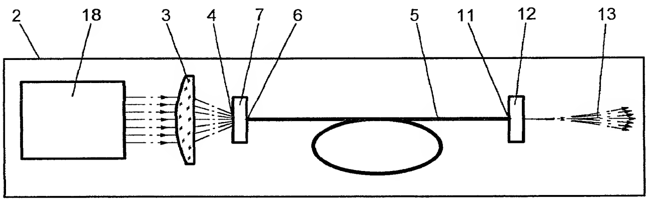


Fig. 2

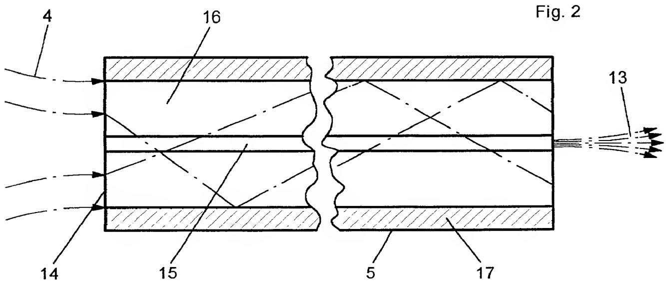


Fig. 2a

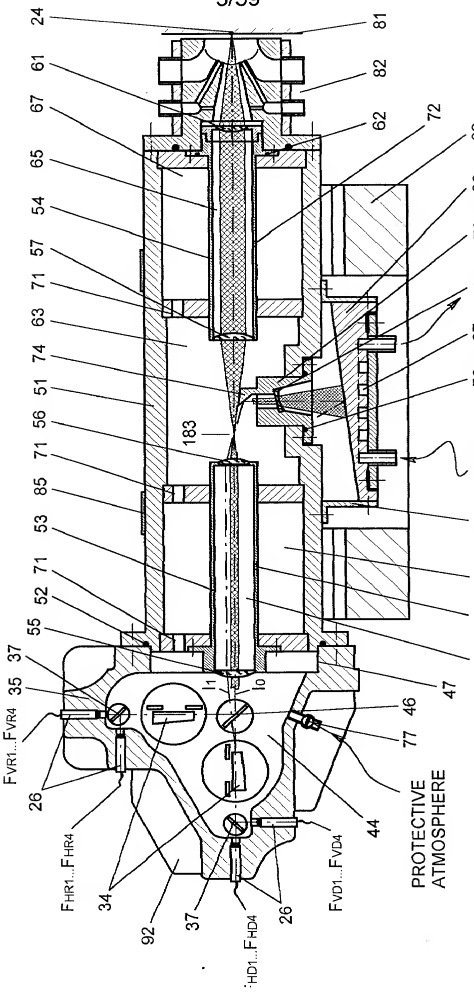
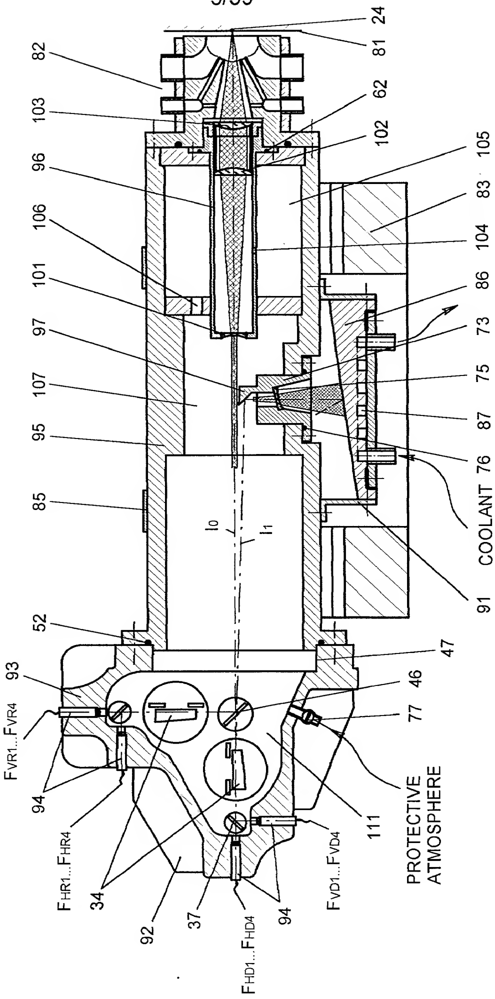

COOLANT
PROTECTIVE ATMOSPHERE
$F_{VR1}...F_{VR4}$
$F_{HR1}...F_{HR4}$
$F_{HD1}...F_{HD4}$
$F_{VD1}...F_{VD4}$
I_1
I_0

Fig. 4



24
81
82
62
103
102
96
105
83
106
104
86
101
73
97
75
107
87
95
76
85
COOLANT
l0
l1
91
52
47
93
46
77
FVR1...FVR4
94
111
PROTECTIVE ATMOSPHERE
FHR1...FHR4
34
FVD1...FVD4
92
37
94
FHD1...FHD4

Fig. 4b

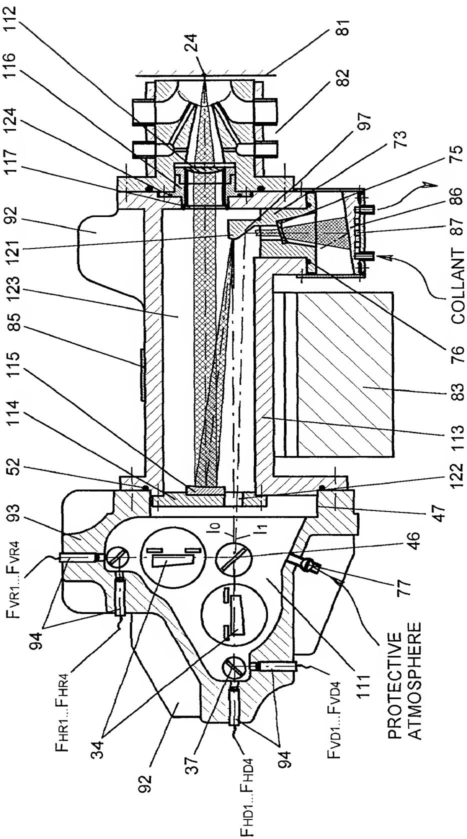

112
116
124
117
92
121
123
85
115
114
52
93
$F_{VR1}...F_{VR4}$
94
$F_{HR1}...F_{HR4}$
34
92
37
$F_{HD1}...F_{HD4}$
94
$F_{VD1}...F_{VD4}$
PROTECTIVE ATMOSPHERE
111
77
46
I_0
I_1
47
122
113
83
76
COLLANT
87
86
75
73
97
82
81
24

Fig. 4c

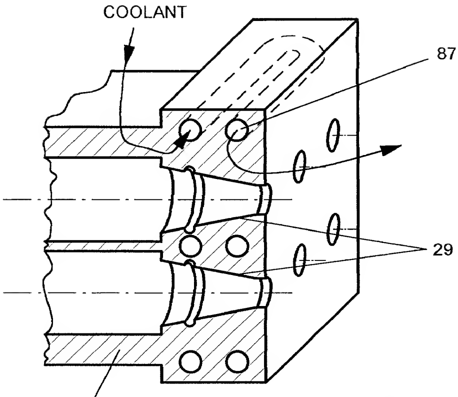


Fig. 8

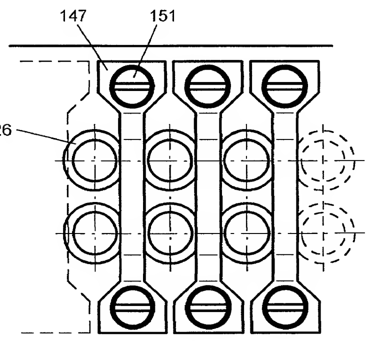


Fig. 8a

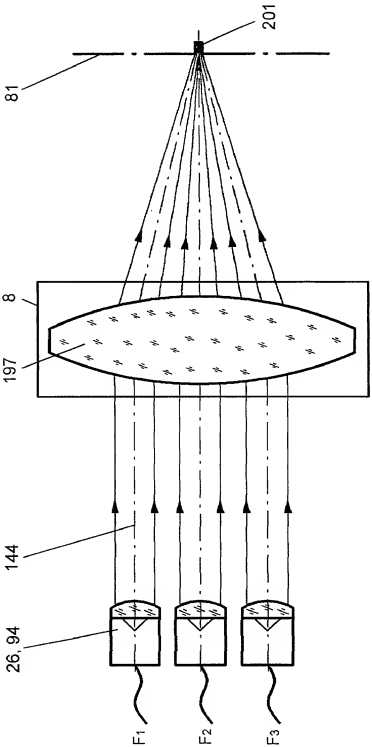


Fig. 31

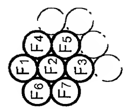


Fig. 30

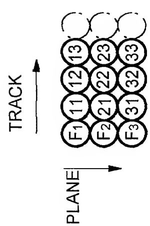


Fig. 29

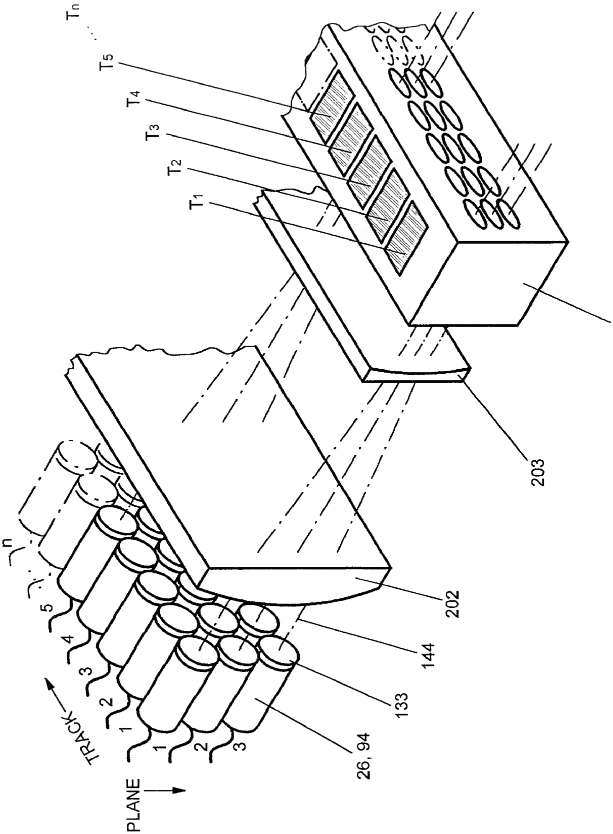


Fig. 32

10978742

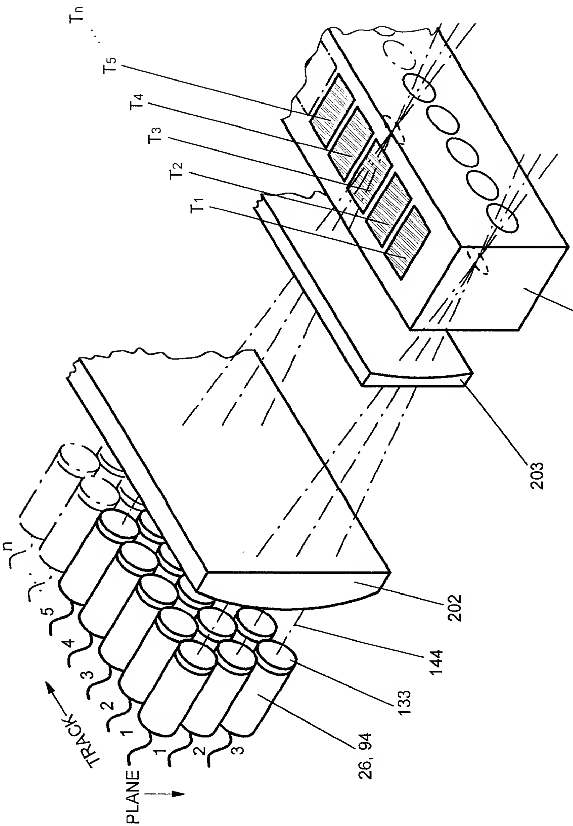


Fig. 33

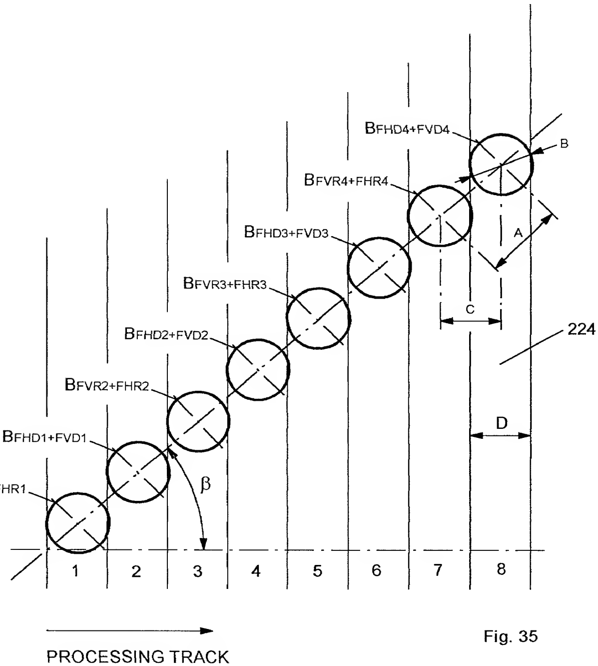

BFHD4+FVD4
B
BFVR4+FHR4
BFHD3+FVD3
A
BFVR3+FHR3
C
224
BFHD2+FVD2
BFVR2+FHR2
D
BFHD1+FVD1
β
BFVR1+FHR1
1
2
3
4
5
6
7
8
PROCESSING TRACK

Fig. 35

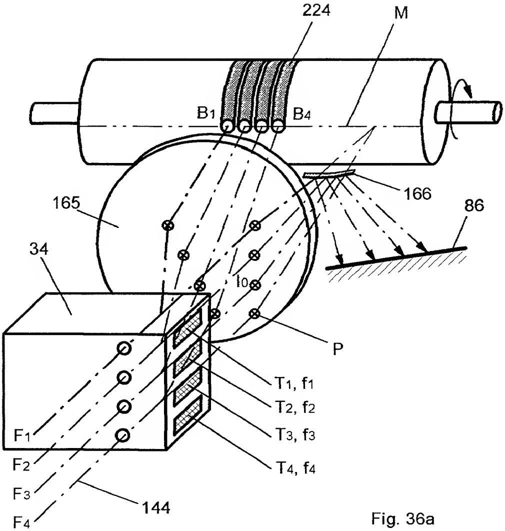


Fig. 36a

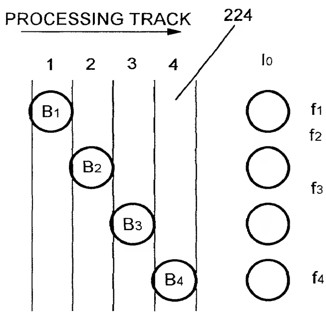


Fig. 36

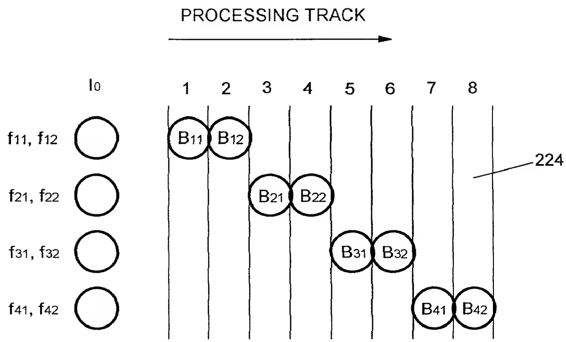

PROCESSING TRACK
I_0
1
2
3
4
5
6
7
8
f_{11}, f_{12}
B_{11}
B_{12}
f_{21}, f_{22}
B_{21}
B_{22}
f_{31}, f_{32}
B_{31}
B_{32}
f_{41}, f_{42}
B_{41}
B_{42}
224

Fig. 37

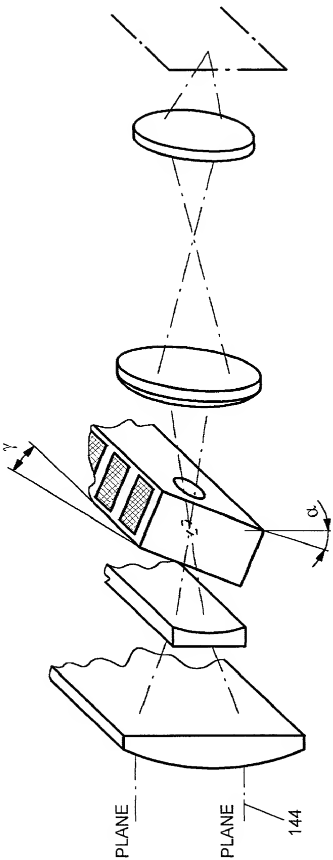


Fig. 38

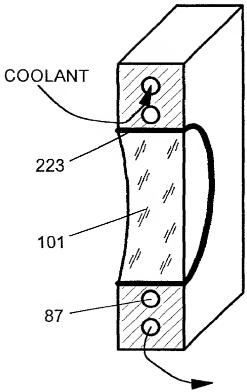


Fig. 39

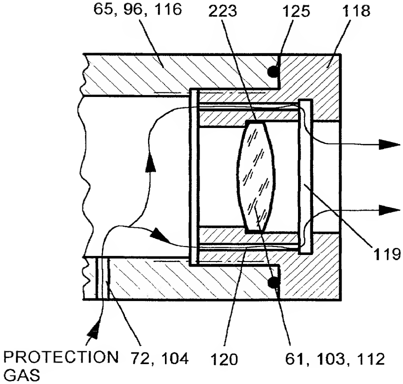


Fig. 39a

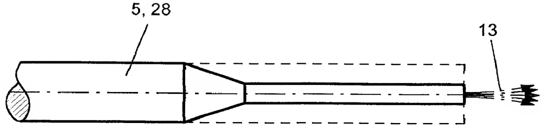


Fig. 40

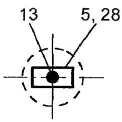


Fig. 40a

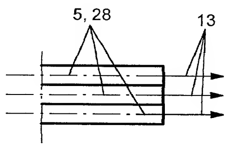


Fig. 40b

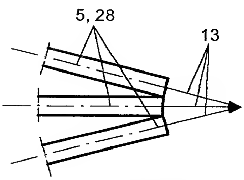


Fig. 40c

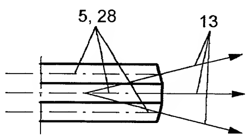


Fig. 40d

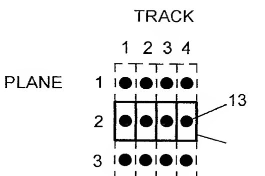


Fig. 41

09/786742
JC02 Rec'd PCT/PTO 08 MAR 2001

LASER RADIATION SOURCE

The invention is directed to a laser radiation source, preferably for processing materials, as well as to an arrangement for processing material comprising a laser radiation source and to the operation thereof.

When processing materials with focused energy beams such as, for example, electron beams or laser beams, there are applications wherein structures must be produced that make high demands of the focused energy beam with respect of its beam geometry and the focusability of the beam. At the same time, however, a high steel [sic] power is required.

A typical case wherein extremely fine structures must be produced on a processing surface is the production of printing forms, whether for rotogravure, offset printing, letter press printing, silk screening or flexo-printing or for other printing processes. In the production of printing forms, it is necessary to produce extremely fine structures on the surface of the printing forms, since highly resolved image information such as text, rastered images, graphics and line work must be reproduced with the surface of the printing forms.

In rotogravure, the printing forms were produced in the past with etching, which had led to good results; the etching, however, was replaced over the course of time by more environmentally friendly engraving with electromagnetically driven diamond stylii. Printing cylinders whose surface is composed of copper are normally employed as printing forms in rotogravure, these fine structures required for the printing being engraved thereinto in the form of cups with the diamond stylus. The printing cylinders are introduced into a printing press after they are produced, the cups being filled with ink therein. Subsequently, the excess ink is removed with a doctor and the remaining ink is transferred onto the printed matter during the printing process. Copper cylinders are thereby employed because of their long service life in the printing process. A long service life is required given large editions, for example, in particular, in magazine printing or packaging printing, since the

surface of the printing form wears in the printing process as a result of the influence of the doctor and of the printed matter. In order to extend the service life even further, the printing cylinders are provided with a copper layer that has been galvanized on or, on the other hand, solid cylinders of copper are employed. Another possibility of making the service life even longer is comprised in galvanically chrome plating the copper surface after the engraving. In order to achieve an even longer surface life, what is referred to as "hot chrome plating" is additionally applied, whereby the galvanic process is carried out under elevated temperature. The longest service lives that could previously be obtained were achieved therewith. Deriving therefrom is that copper is the most suitable as material for the surface of rotogravure cylinders. Materials other than copper have not hitherto proven themselves for large editions.

When producing the cups, the drive of the diamond stylus ensues via an electromechanically driven magnet system having an oscillating armature to which the diamond stylus is secured. Such an electromechanical oscillatory system cannot be made arbitrarily fast because of the forces that must be exerted in order to engrave the cups. This magnet system is therefore operated above its resonant frequency so that the highest engraving frequency, i.e. the highest engraving speed can be achieved. In order to increase the engraving speed even further, a number of such engraving systems have been arranged side-by-side in axial direction of the copper cylinder given current engraving machines. This, however, still does not suffice for the short engraving time of the printing cylinders required currently, since the engraving time directly influences the current nature of the printing result. For this reason, rotogravure is not employed for newspaper printing but mainly for magazine printing.

Upon utilization of a plurality of engraving systems, a plurality of what are referred to as lanes are simultaneously engraved into the surface of the printing cylinder. For example, such a lane contains one or more entire magazine pages. One problem that thereby arises is that cups having different

volumes are generated in the individual lanes given the same tone value to be engraved, this occurring because of the different engraving systems that are driven independently of one another and leading to differences in the individual lanes that the eye detects during later observation. For this reason, for example in packaging printing, only one engraving system is employed so that these errors, which are tolerated in magazine printing, do not occur.

When engraving the cups, the cup volume is varied dependent on the image content of the master to be printed. The respective tone value of the master should thereby be reproduced exactly as possible during printing. When scanning the masters, the analog-to-digital converters having, for example, a resolution of 12 bits are utilized for recognizing the tone value gradations for reasons of image signal processing (for example, gradation settings), this corresponding to a resolution of 4096 tone values in this case. The signal for the drive of the electromagnetic engraving system is acquired from these high-resolution image information, said signal usually being an 8-bit signal, this corresponding to a resolution into 256 tone value gradations. In order to generate the corresponding volumes that are required for achieving this scope of gradations, the penetration depth of the diamond stylus into the copper surface is varied with the drive of the magnet system, whereby the geometry of the cups changes between approximately 120 μm diameter given a depth of 40 μm and approximately 30 μm diameter given a depth of 3 μm. Because only an extremely small range of variation in the depth of the cups between 40 μm and 3μm is available, the penetration depth of the stylus with which the cups are engraved must be exactly driven to fractions of a μm in order to reproducibly achieve the desired range of gradation. As can be seen therefrom, an extremely high precision is required in the engraving of the cups, at least as regard the generation of the required diameters and depths of the cups. Since the geometry of the engraved cups is directly dependent on the shape of the stylus, extremely high demands are also made of the geometry of the diamond stylus which, as has been shown, can only be achieved with extremely high outlay and

with a high rejection rate in the manufacture of the stylii. Moreover, the diamond stylus is subject to wear since, when engraving a large printing cylinder having fourteen lanes, a circumference of 1.8m and a length of 3.6m given a screen of 70 lines/cm - which corresponds to a plurality of 4900 cups/cm^2, a stylus must engrave approximately 20 million cups. When one of the diamond stylii breaks off during the engraving of a printing cylinder, then the entire printing cylinder is unuseable; on the one hand, this causes a considerable financial loss and, on the other hand, represents a serious loss of time since a new cylinder must be engraved, postponing the start of printing by hours. For this reason, users frequently replace stylii earlier than necessary. As can also be seen therefrom, the endurance of the diamond stylii is also a critical concern.

All in all, electromagnetic engraving is well-suited for producing high-quality rotogravure cylinders; however, it has a number of weak points and is extremely complicated and one would like to eliminate these disadvantages with a different method.

The cups produced in this way, which are intended to accept the ink later, are also arranged on the surface of the printing form in conformity with a fine, regular screen, namely the printing screen, whereby a separate printing cylinder is produced for each ink, and whereby a different screen having a different angle and different screen width is respectively employed. Given these screens, narrow webs remain between the individual cups, these supporting the doctor when printing in the printing press that removes the access ink after the inking. Another disadvantage of this operating mode of this electromechanical engraving is that texts and lines must also be reproduced rastered, which leads to step-patterns in the contours of the written characters and the lines that the eye perceives as being disturbing. This is one advantage compared to the widespread offset printing wherein this stepping can be kept in order of magnitude lower, which can then no longer be perceived by the eye, and

leading to a better quality that rotogravure could hitherto not achieve. This is a serious disadvantage of the rotogravure process.

In rotogravure, no stochastic screens can be generated wherein the size of the cups and the position of the cups can be randomly distributed corresponding to the tone value; this, however, is not possible when engraving with the diamond stylus. Such stochastic screens are also frequently referred to as "frequency-modulated screens" that have the advantage that details can be reproduced far better and that no Moirè, this also leading to a better image quality than in rotogravure.

It is also known to utilize the electron beam engraving method applied in the processing of materials for generating the cups, this having exhibited extremely good results because of the high energy of the electron beam and the incredible precision with respect to the beam deflection and beam geometry.

This method is described in the publication, "Schnelles Elektronenstrahlgravierverfahren zur Grvur von Metallzylindern", Optik 77, No. 2 (1987) pages 83-92, Wissenschaftliche Verlagsgesellschaft mbH Stuttgart. Due to the extremely high outlay that is required for the hardware and electronics, electron beam engraving has hitherto not prevailed in practice for the engraving of copper cylinders for rotogravure but only in the steel industry for surface engraving of what are referred to as textured drums for sheet metal manufacture wherein textures are rolled into the sheets.

It has been repeatedly proposed in the trade literature as well as in the patent literature to engrave copper cylinders with lasers. Since copper, however, is an extremely good reflector for laser radiation, extremely high powers and, in particular, extremely high power densities of the lasers to be employed are required in order to penetrate into the copper and melted. There has hitherto not been any laser engraving unit with laser radiation sources having a correspondingly high powered density and energy with which one succeeds in providing the copper cylinders for rotogravure with the required cup structure in the copper surface.

Attempts have nonetheless been made to utilize lasers for rotogravure in that a switch has been made to materials other than copper. Thus, for example, the publication DE-A-19 20 323 has proposed to prepare copper cylinders such with chemical etching that the surface of the copper cylinder already comprises cups that have a volume that corresponds to the maximum printing density. These cups are filled with a solid filler material, for example plastic. As much of the filler material is then removed with a laser until the desired cup volume has been achieved. This method in fact manages with lower laser power than would be necessary in order to melt and evaporate the copper as in electron beam engraving. In this method, however, the remaining plastic is attacked by the solvent of the ink in the printing process and decomposed, so that only a low print run is possible. This method has not proven itself in practice and has thus not been utilized.

The publication of the VDD Seminar Series, "Direktes Lasergravierverfahren für metallbeschichtete Tiefdruckzylinder", published within the framework of a "Kolloquium vom Verein Deutscher Druckingenieure e.V. und dem fachgebiet Druckmaschinen und Druckverfahren, Fachbereich Maschinenbau, technische Hochschule Darmstadt", by Dr. phil. Nat. Jakob Frauchiger, MDC Max Dätwyler, AG, Darmstadt, 12 December 1996, has proposed that rotogravure cylinders plated with zinc be engraved by a quality-switched Nd:YAG high-power solid-state laser pumped with arc lamps. In this method, the volume of the cups is defined by the optical power of the laser. The laser power required for the engraving is transmitted onto the cylinder surface via an optical fiber whose output is imaged onto the cylinder surface through a variable focusing optics. One disadvantage of this method is that the arc lamps required for pumping the laser have a relatively short service life and must be replaced after approximately 500 hours of operation. The engraving cylinder becomes unuseable given a failure of the pump light source during the engraving. This corresponds to a failure of the diamond stylus in electromechanical engraving and results in the same

disadvantages. A preventative replacement of the arc lamps is cost-intensive and work-intensive, particularly since one must count on the fact that the laser beam must be re-adjusted in position after the replacement of the lamps. These lamp-pumped solid-state lasers also have a very poor efficiency since the laser-active material absorbs only a slight fraction of the available energy from the pump source, i.e. from the arc lamp here, and converts into laser light. Particularly given high laser powers, this means a high electrical connection value, high operating costs for electrical energy and cooling and, in particular, a considerable outlay for structural measures due to the size of the laser and cooling unit. The space requirements are so high that the laser unit must be located outside the machine for space reasons, this in turn be accompanied by problems in bringing the laser output onto the surface of the printing cylinder.

A critical disadvantage of this method is comprised therein that zinc is significantly softer than copper and is not suitable as surface material for printing cylinders. Since the doctor with which the excess ink is removed before printing in the printing press is a steel blade, the zinc surface is damaged after a certain time and the printing cylinder becomes unuseable. A printing cylinder having a surface of zinc therefore does not even begin to approach as long a service life in printing as a printing cylinder having a surface of copper. Printing forms having a zinc surface are therefore not suitable for high press runs.

Even if the zinc surface is chrome-plated after the engraving, as has been also proposed - in order to lengthen the service life, the durability does not come close to that of normal copper cylinders. Chrome does not adhere to zinc as well as it adheres to copper and what is referred to as "hot chrome plating", which is successfully employed given copper cylinders in order to achieve an optimum adhesion of the chromium on the copper, is not possible given zinc since the zinc would thereby melt. Since the chrome layer does not adhere very well on the zinc, it is likewise attacked by the doctor blade, which leads to a relatively early failure of the printing cylinders. When, in contrast thereto,

copper cylinders are chrome-plated according to this method, then incredibly high press runs are possible since the chromium firmly adheres on the copper surface, so that these copper cylinders out perform the chrome-plate zinc cylinders by far.

It proceeds from the publication EP-B-0 473 973, which is likewise directed to the method described above, that an energy of 6 mWsec is required in this method given zinc for cutting a cup having a diameter of 120 μm and a depth of 30 μm. An energy of 165 mWsec is recited in this publication for copper, this amounting to a factor of 27.5 for the required laser power. Lasers having a continuous-wave performance of several kilowatts given good beam quality are thus required in order to produce cups in copper with a speed that is accessible for the printing industry. Such a power, however, cannot be produced with the laser arrangement described above. For this reason, it is likewise only possible to engrave a zinc surface.

Such a laser arrangement, which is composed of a single solid-state laser, in fact makes it possible to process rotogravure cylinders having a zinc surface; if, however, one wishes to utilize the advantages of the copper surface and stay with copper cylinders and engrave these with a laser, the high power density required for penetration into the surface of the copper and the high energy required for melting the copper must be inevitably exerted. This, however, has not hitherto been successfully done with a solid-state laser.

It is known that the beam quality in solid-state lasers, i.e. the focusability, decreases with increasing power. Even if the power of the solid-state lasers were to be driven up or if a plurality of solid-state lasers were directed onto the same cup or parts thereof, it would therefore not be possible to satisfactorily engrave copper cylinders for rotogravure with such a laser because the precision of the laser beam, as offered by the electron beam, required for generating the fine structures cannot be achieved. If the laser power were increased given this apparatus, then a further problem would arise: the focusing of high radiant intensity in optical fibers is, as known, difficult.

The fibers burn at high power as a consequence of maladjustment at the infeed location. If one wishes to avoid this, however, the fiber diameter would have to be enlarged which, however, in turn has the disadvantage that the fiber diameter would have to be imaged onto the processing page [sic] with even greater demagnification. A demagnified imaging, however, leads to an increase in the numerical aperture on the processing page and, consequently, to a reduced depth of field on the processing surface. As proposed, the distance from the processing surface could be kept constant. When, however, the beam penetrates into the surface of the material, then a defocussing automatically derives. This having a disadvantageous influence on the required power density and on the exact dot size. Since, however, the diameter of the processing spot and the energy of the beam determine the size of the cup, it then becomes difficult to make the cup size exactly as required by the desired tone value. To this end, it would also be necessary that the laser power is exactly constant and also remains constant over the entire time that is required for a cylinder engraving. When this is not the case, the cup size changes and the cylinder becomes unuseable. This cannot be compensated by varying the size of the processing spot since it is not possible to adequately vary the processing spot in shape.

Further, a complicated modulator is required given such an arrangement. As known, modulators for extremely high laser powers are slow, this leading to a reduction of the modulation frequency and, thus, of the engraving frequency. When, however, the engraving frequency is too low, the energy diffuses into the environment of the processing spot on the processing surface without cutting out a cup. It is therefore necessary to also exert a high power in addition to the high energy for the cutting.

The publication “Der Laser in der Druckindustrie”, by Werner Hülsbuch, page 540, Verlag W. Hülsbusch, Constanc, describes that it is particularly a matter of a high powered density in processing materials given power densities of typically above 10^7 through 10^8 W/cm^2, a spontaneous

evaporation of the material occurs in all materials, this being accompanied by a sudden absorption rise, which is especially advantageous since the laser power is then no longer reflected from the metal surface. When, for example, a laser source of 100 W is available, then the processing spot dare not be larger than 10 μm in order to arrive at these values in the region, as proceeds from the following equation: 100 W : (0.001 cm x 0.001 cm) = 10^8 W/cm^2.

An object of the present invention is to improve a laser radiation source, preferably for processing materials, as well as an arrangement for processing materials having a laser radiation source and the operation thereof such that an extremely high power density and energy are achieved in a cost-beneficial way, and such that both the beam shape with respect to flexibility, precision and beam positioning as well as the beam power can be exactly controlled even given significantly higher laser powers.

This object is achieved by the features of claims 1 through 27 with respect to the laser radiation source.

Advantageous developments and improvements with respect to the apparatus for processing materials with the laser beam source and the operation thereof are recited in the subclaims.

This laser radiation source is composed of a plurality of diode-pumped fiber lasers whose output radiation beams impinge the processing location next to one another and/or over one another or in a point or bundle and thus enables the generation of a processing spot that is designationally variable in shape and size, even given extremely high laser powers and extremely high power densities. According to the invention, these fiber lasers can be implemented as continuous wave lasers or as quality-switched lasers, also referred to as Q-switch lasers, whereby they are advantageously internally or externally modulated and/or comprise an additional modulator. Q-switch lasers have an optical modulator available to them within the laser resonator, for example an acousto-optical modulator, that, in its opened condition, interrupts the laser effect given a pump radiation that continues to exist. As a

result thereof, energy is stored within the laser resonator, this being output as a short laser pulse having high power when the modulator is closed in response to a control signal. Q-switch lasers have the advantage that they emit short pulses having high power, which briefly leads to a high power density. An advantageous elimination of the molten and evaporated material is enabled in the pulsed mode due to the brief-term interruptions in the processing event. Instead of switching the quality, a pulsed mode can also be generated with internal or external modulation.

The processing spot can be designationally modified in shape and size in that different pluralities of the lasers that are provided can be switched on for shaping the processing spot. It is thereby especially advantageous that the depth of the cut cup can be determined by the laser energy independently of its shape and size. Further, a control of the energy of the individual lasers can also generate any arbitrary beam profile within the processing spot and, thus, any arbitrary profile within the cup as well.

Further advantages of the present invention compared to known laser radiation sources are comprised therein that the infeed of the radiant power from a solid-state laser into an optical fiber can be eliminated but the exit of the fiber laser supplies diffraction-limited radiation that, according to the invention, can be focused onto less than a 10 μm diameter, as a result whereof an extremely high power density is achieved given the greatest possible depth of field.

Given a traditional arrangement with solid-state lasers, the size of the processing spot lies in the region of approximately 100 μm. Given the present invention, thus, a power density that is improved by the factor 100 derives, and a design possibility in the area of the processing spot that is improved by the factor 100 derives.

Due to the high precision and due to the processing spot that can be designed in very fine fashion, extremely fine screens, also including the stochastic screens that are also called frequency-modulated screens (FM screens)

and, thus, extremely smooth edges in lines and written characters can be economically produced, so that rotogravure no longer need be inferior to offset printing in terms of printing quality.

Due to the operating mode of the inventive laser radiation source, it is also possible to link arbitrary raster widths to arbitrary screen angles and apply arbitrary different screen widths and arbitrary different screen angles at arbitrary locations on the same printing cylinder. Line patterns and text can also be applied independently of the printing screen as long as one sees to sufficient supporting locations for the doctor blade.

One advantage of the invention is comprised therein that the differences in the data editing for the production of the printing form are reduced to a minimum between rotogravure and offset printing, this yielding substantial cost and time savings. Up to now, the data for the rotogravure are acquired by conversion from the data already present for the offset printing because a signal is required for the drive of the engraving system that defines the volume of a cup, whereby the area of a screen dot is determined in offset printing. As a result of the multiple arrangement of lasers, the inventive laser beam source makes it possible to vary the area of a cup given constant depth, for which reason it is no longer required to convert the data for offset printing into data for the rotogravure. The data for the offset printing can be directly employed for engraving the rotogravure forms.

Another advantage of the invention is comprised therein is that both the area of a cup as well as the depth can be controlled independently of one another with this laser beam source, this leading thereto that a greater plurality of tone value gradations can be reproducibly generated, this leading to a more stable manufacturing process for the printing cylinders and to an improved printing result.

It is also a critical advantage that the energy can be unproblemmatically transported from the pump source to the processing point with the fiber, namely the fiber laser itself, or with a fiber that is welded on or, respectively,

attached in some other way, this yielding an especially simple and space-saving structure.

Another advantage of the invention is comprised therein that the efficiency of such an arrangement with fiber lasers is significantly higher than the efficiency of solid-state lasers, since absorption efficiencies of more than 60% are achieved for fiber lasers, these lying only at approximately half given traditional dialed-pumped solid-state lasers and being even far lower given lamp-pumped solid-state lasers. Given the required power of several kilowatt for an efficient engraving of rotogravure cylinders, the efficiency of the lasers is of incredible significance for the system costs and the operating costs.

Further, a multiple arrangement of lasers yields the advantage that the outage of a laser is less critical than given a single-channel arrangement. When the only laser that is present given the single-channel arrangement fails during the engraving of a printing cylinder, the entire printing cylinder is unuseable. When, however, a laser fails given a multiple arrangement, then the power of the remaining lasers can, for example, be slightly boosted in order to compensate the failure. After the end of the engraving, the laser that has failed can then be replaced.

The dissertation, "Leistungsskalierung von Faserlasern", Physics Department of the University of Hannover, Dipl.-Phys. Holger Zellmer 20 June 1996, fiber lasers are discussed as being known. These lasers, however, had already been proposed by Snitzer and Köster, without these having been previously utilized for processing materials given high powers. Although powers of up to 100 W can be fundamentally achieved with the lasers described in this dissertation, no useable arrangements are known for utilizing these lasers for purposes of the present invention.

The publication WO-A-95/16294 has already disclosed phase-coupled fiber lasers; however, these are extremely involved in terms of manufacture and are not suitable for industrial employment. It had hitherto not been recognized

to bring lasers of this simple type to high power density and energy in the proposed, simple way and to utilize them for erosive processing of materials.

For example, the resonator length of the individual lasers must be kept exactly constant to the fraction of a micrometer, to which end what are referred to as "piezoelectric fiber stretchers" are utilized. As a result of the complex structure, it is likewise not possible to construct the laser unit modularly, i.e. of components that are simple to assemble and to be multiply employed or to replace individual laser components as needed on site as a consequence of the great plurality of optical components within a phase-coupled laser, moreover, the optical losses are extremely high, and the pump radiation absorption of the laser-active medium is low, which results in a low efficiency of the arrangement. Although fiber lasers are not particularly susceptible to back-reflections in and of themselves phase-coupled lasers exhibit a great sensitivity to back-reflections due to their very principle, i.e. when portions of the emitted radiation proceed back into the laser resonator due to reflection or dispersion, as is unavoidable when processing materials. These back-reflections lead to uncontrolled output amplitudes and cause the laser to shut down. Although what are referred to as optical isolators are known, these being intended to attenuate such back-reflections, these involve a number of disadvantages in practice, which, for example, include the optical losses, the high price and the inadequate attenuation properties. The lasers for the inventive purpose of processing materials need not only exhibit a high power density but also must be able to supply the required energy for cutting out the cups, must be extremely stable in terms of the emitted radiation and must have a very good efficiency.

Further, US-A-5,694,408 has disclosed a laser system wherein a master oscillator generates low-power radiation energy at a specific wavelength, this being optically intensified and it being distributed for further post-amplification onto a plurality of post-amplifiers, in order to then be in turn united to form a common beam, a precise phase readjustment of the individual post-amplified

signals being required for this purpose in order to avoid interferences in the output signal. This requires complicated measuring and control procedures and involved actuating elements, for which end, for example, electro-optical phase modulators must be utilized, these being extremely expensive and having to be operated with extremely high voltages.

Further, US-A-5,084,882 discloses a phase-coupled laser system that employs a plurality of fibers or, respectively, fiber cores in a bundle, the core thereof being, on the one hand, large compared to its cladding or, respectively, its spacing in order to achieve the phase coupling; on the other hand, this should only have a diameter of a few micrometers since it is a matter of single-mode fibers. This system is mainly provided as optical intensifier.

Another phase-coupled laser system that is likewise implemented in an extremely complex way and that is composed of a plurality of what are referred to as "sub-oscillators" is disclosed by GB-A-21 54 364 under the title "Laser Assemblies", having already been disclosed in 1984; however, no industrial realizations with such phase-coupled laser systems have become known up to now.

It has also not been previously proposed to combine a plurality of the initially cited fiber lasers in a simple way, i.e. without a complex phase coupling or the like, to form a compact, rugged and service-friendly radiation source for processing materials and, for example, to employ this for multi-track recording. An inventive, multiple arrangement of such simple lasers that can be cost-beneficially manufactured in quantity in several tracks and levels yields enormous advantages for the purposes of the invention that would certainly not have escaped attention if the invention solution had been known.

A further advantage of fiber lasers is there clearly lower tendency to oscillate when energy proceeds back into the laser. Compared to traditional solid-state lasers, fiber lasers have a resonance overshooting that is lower by an order of magnitude in terms of its transfer function, this having been very positively proven during operation. When processing materials, namely, one

cannot always prevent energy from being reflected from the processing location back into the laser because the melting material is explosively hurled in unpredictable directions and thereby flies through the laser beam before it can be removed and neutralized by particular measures that are presented in one embodiment of the invention.

A critical advantage of the multiple arrangement of fiber lasers without phase coupling is comprised therein that the individual lasers behave differently in case of a back-reflection. This is related to the fact that, for example, some of the lasers are not affected at all by a back-reflection and others may possibly be effected only with a delay. The probability is therefore high that oscillations of the individual lasers, if they occur at all, are superimposed such that they have no negative influence on the quality of the results of the engraving.

The inventive laser radiation source can also be advantageously utilized for all other types of processing materials or transferring materials wherein high power density, high energy and great precision or, too, high optical resolution are important. In addition to engraving rotogravure cylinders having a copper surface, other materials such as, for example, all metals, ceramic, glass, semiconductor materials, rubber or plastics can be processed and/or materials can be stripped more specifically prepared carrier materials and transferred onto other materials at high speed and with high precision. In addition to those that are uncoated, moreover, rotogravure cylinders, printing plates or printing cylinders that are coated with masks as well as all types of printing forms can also be produced or, respectively, processed at high speed and with high resolution for offset printing, letter press printing, silk screening, flexo-printing and all other printing processes. For example, the offset printing plates having metal coating (bi-metal plates) that are employed for printing extremely large print runs in offset printing and similar materials can be provided with images in an environmentally friendly way, this having been hitherto possible only with etching.

Further, materials can be processed that contain a magnetizable surface, in that the parts of the material magnetized large-area by a pre-magnetization process are de-magnetized by briefly heating selected processing points to temperatures that lie above the Curie point, being heated with the inventive laser radiation source. The material provided with images in this way for applications in printing technology can serve as print master in conjunction with a corresponding toner.

As a result of the high power density of the inventive laser radiation source, it is also possible to directly process chromium. Thus, for example, printing cylinders of copper can already be chrome-plated for rotogravure before the laser engraving, this eliminating a work step after the engraving and benefitting the timeliness. Since the printout behavior of a cup engraved in copper is also better than that of a chrome-plated cup and its volume is more precise, this method also yields even better printing results in addition to the high service life as a result of the remaining chromium layer and the improved timeliness.

The employment of the inventive laser radiation source, however, is not limited to employments in printing technology but can be utilized anywhere that it is important to erode material or change the properties of the material by energy irradiation with lasers given high resolution and high speed. Thus, for example, the aforementioned texture drums can also be produced with the inventive laser radiation source. Further, the patterns of interconnects for printed circuit boards, including the boards for the components, preferably for multi-layer printed circuit boards, can be produced by eroding the copper laminate and allowing the interconnects to stand and by eroding copper laminate and carriers at the locations of the bores. Further, the surface structure of material surfaces can be partially modified by partial heating. For example, extremely fine structures having the hardness of material surfaces can be produced large-area in this way, this being particularly advantageous for bearing surfaces since the bearing properties can be intentionally influenced in

this way. Further, there are non-conductive ceramic materials at whose surface metal crystallizes out due to energy irradiation, this being capable of being utilized in conjunction with the inventive laser radiation source for applications that require a high resolution, for example for producing interconnects.

The laser beams can thereby be guided to the processing spot in the greatest variety of ways and can be moved across the material; for example, the material to be processed can be located on a rotating drum past which the radiation source is conducted in relative fashion. However, the material can also be located in a plane over which the laser radiation source or its output radiation is conducted past in relative fashion. In a flat bed arrangement as presented in the aforementioned publication "Der Laser in der Druckindustrie" von W. Hülsbusch, Figure 7-28 on page 431 and as likewise disclosed in the publication EP-A-0 041 241, the radiation source presented therein as argon or He Ne laser or, respectively, as laser light source (4) in Figure 3 of the publication can be replaced by the inventive laser radiation source in order to utilize the advantages of the inventive laser radiation source. Further, the material to be processed can be located within a hollow cylinder over which the laser radiation source or its output radiation sweeps in a relative motion.

Inventively, the output of the laser radiation source can also be implemented with a variable plurality of tracks whose mutual spacings are variable, preferably similar to a long comb, this moving relative to the material to be provided with images. Such an arrangement is disclosed by US-A-5,430,816. It is disclosed therein to direct the radiation of an excimer laser having a strength of approximately 50 watts onto a bundle of what are referred to as stepped index fibers having diameters of 50 through 800 micrometers and to respectively couple a part of the radiation into the individual fibers. The exit of each fiber is then imaged onto the workpiece via a respective positive lens having a diameter of 60 mm, whereby the spacing between the individual processing points must amount to at least 60 mm and a protective mechanism to prevent contamination is required per positive lens. What is disadvantageous

is that only a fraction of the laser energy thus proceeds into the respective fibers, the energy distribution turns out very differently and changes in the exit power derive given movement of the fibers, for which reason what are referred to as scramblers must be utilized in order to avoid this; these, however, disadvantageously influence the efficiency of the system and increase the costs. Only relatively imprecise bores having a diameter of approximately 130 micrometers can be produced in plastic with such an arrangement. The pulse rate of the laser is the same for all simultaneously produced bores, so that all bores must be implemented of the same size. Moreover, the system is relatively slow since a boring processing lies between one and two seconds. An arrangement having fiber lasers yields tremendous advantages compared thereto; the speed can be increased by several orders of magnitude and metals can also be processed; the precision is substantially greater since fiber lasers also exhibit a stable output power given movement of the laser fibers; and bores having diameters below 10 micrometers can also be unproblemmatically produced. Since each fiber laser can be separately modulated, different processing patterns are possible. Further, the end sections of the fiber lasers can be unproblemmatically implemented smaller than 2.5 mm in diameter, this enabling a clearly smaller spacing between the processing tracks. As a result thereof, it is also possible to employ a shared protective mechanism to prevent contamination of the optics.

Another example for the application of the inventive laser beam source wherein the material is preferably arranged in a plane derives in the semiconductor industry in the processing of what are referred to as wafers, i.e. usually circular disks of suitable semiconductor material that, for example, are incised or cut or can be provided with all conceivable patterns in the surface, of a type that could previously be manufactured only by time-consuming chemical etching processes that were also not environmentally friendly.

For the multi-channel cutting and in sizing of materials, a simplified embodiment of the laser radiation source is inventively possible, as disclosed in

the German Patent Application P 198 40 936.2 of the assignee, "Anordnung zum mehrkanaligen Schneiden und Ritzen von Materialien mittels Laserstrahlen".

A further inventive application of the laser radiation source is established in the manufacture of monitors and displays. For example, the apertured masks for color picture screens as well as the masks of what are referred to as flat picture screens or LCD displays can be manufactured in a more environmentally friendly way with laser processing than with the chemical etching processes that were previously employed, in that the inventive laser radiation source is applied.

A considerable advantage of the inventive laser radiation source is that it has a small volume and has a flexible connection, namely the laser fibers or fibers connected thereto between the pump source and the exit of the radiation at the processing location and thus allows all conceivable operating positions of the laser radiation source or of its beam exit. There are therefore also no limitations for the spatial arrangement of the processing surface, since they can be arranged in an arbitrary attitude in space.

Another advantage of the invention is comprised therein that the radiation beam of the individual lasers with defined values in beam diameter, beam divergence centering and angular direction can be exactly and durably acquired in a terminating section (terminator), as a result whereof a fabrication-suited and service-suited arrangement for forwarding the laser radiation onto the processing surface can be created. Inventively, the radiation beams can thereby be coupled into the fiber dependent on the application, for example as pump spot and/or can be coupled out as parallel laser beam, can diverge at the exit location or, for example, can be focused in a certain distance from the exit point. There is thereby a desire to fashion the terminator as small as possible and to provide it with one or more fits as reference surface or reference surfaces for the alignment of the laser beam.

According to the invention, this is achieved in that the optical fibers are set in the terminator and the position of the optical fibers and/or the position of the emerging radiation beam is exactly adjusted. On the basis of the exact adjustment and of an inventive, correspondingly spatially small embodiment of the terminators which can also be attached to one another in an especially simple way as a result of a special shaping, it becomes possible to combine the radiation beams of a plurality of fiber lasers and focus them such that the respectively encountered object is achieved and, at the same time, an economical manufacture as well as a cost-beneficial maintenance of the laser radiation source is enabled.

The invention is explained in greater detail below on the basis of Figures 1 through 44a.

Shown are:

Fig. 1	a schematic illustration of the laser radiation source;
Fig. 2	a fundamental illustration of the fiber laser (prior art);
Fig. 2a	an attenuated illustration of the fiber of the fiber laser (prior art);
Fig. 3	a cross-section through an arrangement for processing material with an inventive laser radiation source;
Fig. 4	an illustration of a laser gun for the inventive laser radiation source having a multiple arrangement of fiber lasers;
Fig. 4a	a perspective illustration relating to Fig. 4;
Fig. 4b	a version of Fig. 4;
Fig. 4c	a further version of Figs. 4 and 4b;
Fig. 5	an example of a terminator for the outfeed of the radiation from a fiber or, respectively, from the fibers of a fiber laser;
Fig. 5a	an example of a multiple arrangement for a plurality of terminators;
Fig. 5b	an example of a terminator having adjustment screws;
Fig. 5c	a cross-section through the terminator according to Fig. 5b in the region of the adjustment screws;

Fig. 6	an example of a terminator having spherical adjustment elements;
Fig. 6a	a cross-section through the terminator according to Fig. 6 in the region of the spherical adjustment elements;
Fig. 7	an example of an embodiment of a terminator having a conical fit for insertion into a mount;
Fig. 8	an example of a multiple mount for a plurality of terminators;
Fig. 8a	the rear fastening of the terminators according to Fig. 8;
Fig. 9	an example of an embodiment having quadratic cross-section;
Fig. 9a	a cross-section through the terminator according to Fig. 9;
Fig. 10	an example of a terminator having rectangular cross-section and a trapezoidal plan view;
Fig. 10a	a longitudinal section through the terminator according to Fig. 10;
Fig. 10b	a cross-section through the terminator according to Fig. 10;
Fig. 11	an example of a terminator having trapezoidal cross-section;
Fig. 11a	an example of a terminator having triangular cross-section;
Fig. 12	an example of a terminator having honeycomb-shaped cross-section;
Fig. 13	a modular implementation of the fibers of the fiber laser according to Fig. 1;
Fig. 14	an example of the infeed of the pump energy into the fibers of the fiber laser according to Fig. 13;
Fig. 15	an example of a fiber laser having two outputs;
Fig. 16	an example of the merging of two fiber lasers;
Fig. 17	a schematic illustration of the beam path through an acousto-optical deflector or, respectively, modulators;
Fig. 18	blanking out unwanted sub-beams of an acousto-optical deflector or, respectively, modulators;
Fig. 18a	an arrangement having an electro-optical modulator;

Fig. 19	a plan view onto a four-channel acousto-optical modulator;
Fig. 19a	a section through the modulator according to Fig. 19;
Fig. 20	a schematic beam path for a plan view for Fig. 4;
Fig. 21	a schematic beam path for a plan view for Fig. 4b;
Fig. 22	a schematic beam path for a plan view for Fig. 4c;
Fig. 23	a beam path for terminators that are arranged at an angle relative to one another;
Fig. 24	a version of Fig. 23 that contains a multi-channel acousto-optical modulator;
Fig. 24a	a version for Fig. 24;
Fig. 25	an intermediate image for matching the fiber lasers or, respectively, their terminators to, for example, the modulator;
Fig. 26	the merging of twice for tracks of the beam path from terminators with a strip mirror arrangement;
Fig. 26a	a plan view for Fig. 26;
Fig. 27	a view of a strip mirror;
Fig. 27a	a sectional drawing through the strip mirror according to Fig. 27;
Fig. 27b	another example of a strip mirror;
Fig. 28	the combining of twice for tracks of the ray beam from terminators with a wavelength-dependent mirror;
Fig. 28a	a plan view of Fig. 28;
Fig. 29	an arrangement of a plurality of terminators in a plurality of tracks and in a plurality of planes;
Fig. 30	an arrangement of a plurality of terminators in a bundle;
Fig. 31	a sectional view through the ray beam from the terminators of the fiber lasers F1 through F3 according to Fig. 29 or Fig. 30;
Fig. 32	an arrangement having a plurality of terminators in a plurality of tracks and a plurality of levels having a cylindrical optics for matching, for example, to the modulator;

Fig. 33	a modification of Fig. 32;
Fig. 34	a mouthpiece for the laser gun with connections for compressed air and for extracting the material released by the beam;
Fig. 35	a turning of the laser gun for setting the track spacings;
Fig. 36	an illustration for generating four tracks with an acousto-optical multiple deflector or, respectively, multiple modulator;
Fig. 36a	a spatial presentation of an acousto-optical multiple deflector or, respectively, multiple modulators;
Fig. 36b	an expanded embodiment related to Fig. 36a;
Fig. 36c	a plan view of Fig. 36b;
Fig. 37	an illustration for generating multiple tracks with the assistance of an acousto-optical multiple deflector or, respectively, multiple modulator;
Fig. 38	an advantageous arrangement for avoiding reflections back into the lasers;
Fig. 39	a lens that has coolant flowing around it;
Fig. 39a	a section through a mount 4 an objective lens;
Fig. 40	a fiber laser or a fiber that have been clearly reduced in cross-section at their exit end;
Fig. 40a	a plan view onto the end of the fiber laser or the fiber according to Fig. 40;
Fig. 40b	a side view of the fiber end wherein the axes of the emerging ray beams proceed nearly parallel;
Fig. 40c	a side view of the fiber end wherein the axes of the emerging ray beam overlap outside the fiber bundle;
Fig. 40d	a side view of the fiber end wherein the axes of the emerging ray beams overlap within the fiber bundle;
Fig. 41	an arrangement of fiber lasers or fibers according to Fig. 40 in a plurality of tracks and levels;
Fig. 42	a farther embodiment of the laser radiation source;

Fig. 42a	a farther-reaching embodiment according to Fig. 42;
Fig. 42b	a sectional view of Fig. 42a;
Fig. 42c	an illustration of a robot;
Fig. 43	a flat bed arrangement having the inventive laser beam source;
Fig. 43a	an addition to Fig. 43;
Fig. 43b	a sectional drawing through an arrangement for removing the material released during the processing;
Fig. 44	a hollow bed arrangement having the inventive laser beam source; and
Fig. 44a	an addition to Fig. 44.

Fig. 1 shows a laser radiation source that is composed of a plurality of diode-pumped fiber lasers (2), also called fiber lasers, inventively implemented preferably as modules, these being charged with electrical energy by a preferably modular supply 32 that is largely converted into laser radiation. Further, a controller 33 is provided via which the modulation of the radiation is undertaken and that cease to the interaction of the laser radiation source with its periphery. The output rays of the laser enter into an optical unit 8 at the radiation entry 9 and emerge from the optical unit at the radiation exit 10. The job of the optical unit 8 is to shape the laser radiation to form a processing spot 24 on a processing surface 81; however, the laser radiation can also be directly directed on to the processing surface without optical unit.

Figs. 2 and 2a show the fundamental structure of a fiber laser arrangement (2). In Fig. 2, the energy of a pump source such as, for example, a laser diode, called pump source 18 here, is shaped via an infeed optics 3 to form a suitable pump spot 4 and is coupled in to the laser fiber 5. Such pump sources are disclosed, for example, in German Patent Application P 196 03 704 of the assignee. Typical pump cross-sections of the laser fibers lie approximately between 100 μm and 600 μm in diameter given a numerical aperture of approximately 0.4. The laser fiber 5 is provided with an infeed mirror 7 at the infeed side 6 that allows the pump radiation to pass unimpeded but exhibits

100% reflection for the laser radiation. The infeed mirror 7 can be secured to the fiber end with a suitable mount or by gluing; however, it can also be realized on the fiber end by direct vapor-deposition of a suitable layer as employed given infeed mirrors for lasers. An outfeed mirror 12 that is partially reflective for the laser radiation is attached to the outfeed side 11 of the laser fiber 5, the laser radiation 13 being coupled out through said outfeed mirror 12. Advantageously, the outfeed mirror exhibits 100% reflection for the pump radiation. As a result thereof, the remaining pump radiation is reflected back into the optical fiber, which is advantageous since the pump energy is utilized better and, further, does not represent a disturbing factor in the application of the laser radiation. The outfeed mirror can, like the infeed mirror, likewise be produced by vapor-deposition.

The infeed event of the pump radiation into the pump cross-section 14 of the laser fiber 5 is shown in greater detail in Fig. 2a. The energy in the pump spot 4 excites the laser radiation in the core 15 of the laser fiber 5 on its way through the fiber. The pump core 16 is surrounded by a cladding 17. The core of the laser fiber that is approximately 5 μm through 10 μm thick is doped mainly with rare earths.

The relatively large pump cross-section 14 simplifies the infeed of the pump energy and enables the use of a connection between pump source and laser fiber that is simple to release, as shown in Figs. 13 and 14. The terminator of the laser fiber at the side of the pump source can thereby be advantageously structurally the same as the terminator at the outfeed side; however, it need not be. A precise blood-type connection between pump source and laser fiber offers considerable advantages in the manufacture of the fiber laser and in case of service. The laser fiber, however, can also be firmly connected to the pump source to form a laser module. As a result of the intentionally manufactured, extremely small fiber core diameter, the fiber laser supplies a practically diffraction-limited laser radiation 13 at the exit.

Fig. 3 shows a cross-section through one of the inventive embodiments of an arrangement for processing materials with the inventive laser radiation source (1). A drum 22 is rotatably seated in a housing 21 and is placed into rotation by a drive (not shown). A laser gun 23, which is conducted along the drum in axial direction with a carriage (not shown), is located on a prism (likewise not shown).

The laser radiation emerging from the laser gun 23 impinges the surface of the drum at the processing location in the processing spot 24. Either the surface of the drum as well as a material clamped onto the drum surface can be processed. The fiber lasers, whose laser fibers 5 are respectively wound to form, for example, an air-permeated coil 25, are supplied into the laser gun 23 with the inventive terminators 26, 94. Advantageously, however, passive single-mode fibers or other passive optical fibers, refer to in brief as fibers 28, can also be welded to the fiber lasers or coupled thereto in some other way before the terminators 26, 94 are attached, as described in Figs. 15 and 16.

The pump sources 18 of the fiber lasers are attached on a cooling member 27 that diverts the waste heat via a cooling system 31. The cooling system 31 can be a matter of a heat exchanger that delivers the waste heat to the surrounding air; however, it can also be a matter of a cooling unit. The laser gun 23 can also be connected to the cooling system, but this is not shown. The driver electronics for the pump sources 18, which belong to the supply 32 (not shown in further detail), are preferably situated on the cooling member. A machine control is provided for the drives but is not shown in Fig. 3. The structure of the pump sources, fiber laser and appertaining power electronics is preferably modularly implemented, so that corresponding pump sources and power modules of the driver electronics that are separate or combined into groups belong to the individual fiber lasers, these being capable of being connected to one another via a bus system. As explained in greater detail in Fig. 13 and Fig. 14, the laser fibers 5 and the pump sources 18 can be connected to one another via a releasable connection. It is also possible to couple a slight

part of the pump radiation out of the laser fiber 5, for example as a result of a slight injury to the cladding 14, and to conduct this via an optical fiber onto a measuring cell in order to offer a signal therefrom that can be employed for the control or, respectively, regulation of the pump radiation.

The modulation signals for the laser radiation are generated in the controller 33 and the interaction of the laser radiation source with the machine control and with the supply 32 as well as the executive sequence of the calibration events as well as of the control and regulation events are managed in said controller 33. A safety circuit (not shown), for example switches the pump sources permanently off when there is danger.

Although a horizontally seated drum is shown in Fig. 3, the drum can be arranged in any arbitrary attitude since the inventive laser radiation source is completely directionally insensitive in terms of its attitude and is very compact in terms of structure and, moreover, since the laser fibers 5 of the fiber laser or fibers 28 coupled to the laser fibers can be arbitrarily laid; for example, the shaft of the drum can also be seated vertically or inclined from the perpendicular, which yields an especially small floor space. As a result thereof, moreover, the operation of a plurality of arrangements or a system having a plurality of drums is possible on the same floor space as would be required by an arrangement having a horizontally seated drum. As a result thereof, the printing forms can be manufactured faster; in particular, all printing forms for a color set can be produced in a single, parallel pass, which is advantageous especially with respect to the uniformity of the final result. Further, an automatic charging with printing forms for provision with images can be realized better given a system erected on a small floor space than given a spatially larger system. One or more laser radiation sources and, additionally, one or more further lasers can be directed onto the same printing form in order to accelerate the production thereof. One advantage of the multi-track arrangement having the very fine and precise tracks is thereby that potential seams are clearly less disturbing then when recording is carried out with coarser tracks. As described under Fig. 37,

further, the position of the tracks can be precisely re-adjusted, so that residual errors become clearly smaller than a track width. The inventive laser radiation sources can thereby be preferably utilized for processing the finer contours and the further laser or lasers can be utilized for processing rougher contours, which can be particularly employed given printing forms that, for example, are composed of plastic or rubber.

Instead of one or each of the provided fiber lasers 2, it is conceivable to provide a laser system with a terminator into [sic] the laser radiation source and alternatively supply to the laser gun 23, whereby the fiber laser described in detail under Fig. 2, however, represents the more cost-beneficial solution. When processing materials, namely, if the radiant power of a plurality of lasers that are not coupled to one another and that naturally emit with a slight wavelength difference are directed onto a processing spot, a phase equality of the individual lasers can be foregone and an expensive control and regulation technology for a phase coupling that is susceptible to malfunction can be avoided.

Such a laser system that, for example, is disclosed by US-A-5,694,408 contains an optical post-amplification and comprises a radiation output composed of a fiber. A terminator is described in greater detail later in one of the Figures 5, 5a, 5b, 5c, 6, 6a, 7, 9, 9a, 10, 10a, 10b, 11, 11a or 12.

Instead of employing the laser system disclosed by US-A-5,694,408, it is also conceivable to employ a phase-coupled laser system according to US-A-5,084,882. An image of the fiber bundle then derives on the processing surface as the respective processing spot. Alternatively, a single-mode fiber could be welded to each fiber at the exit of the bundle, this could be provided with the respective terminators and supply the laser gun. However, it is extremely difficult and complicated to manufacture such phase-coupled laser systems and they would be correspondingly expensive. Up to now, such phase-coupled laser systems have also not been commercially available.

Fig. 4 is a section through an applied example of a laser gun having sixteen fiber lasers that are coupled via terminators 26 and having a modulation unit composed of two multi-channel acousto-optical modulators 34. The laser gun is a multi-part receptacle for the adaptation of the optical unit and contains mounts 29 (Fig. 4a) with fitting surfaces for the fits of the terminators 26, means for combining the individual laser beams, the modulation unit, a transmission unit for the transmission of the laser radiation that is intended to produce a processing effect onto the processing surface, and an arrangement for neutralizing the laser radiation that is not intended to produce a processing effect. An arrangement for removing the material eroded from the processing surface can be arranged at the laser gun; this, however, can also be arranged in the proximity of the processing surface in some other way.

Fig. 4a shows a perspective illustration relating to Fig. 4.

Fig. 4b shows a modification of Fig. 4 wherein the ray beams of the individual fiber lasers do not proceed parallel as in Fig. 4 but at an angle relative to one another; this, however, cannot be seen from the sectional view in Fig. 4b and is therefore explained in greater detail in Figs. 21, 22 and 24.

Fig. 4c shows a modification of Fig.4b that enables an advantageous, significantly more compact structure as a result of a differently implemented transmission unit.

Fig. 4 shall be explained in detail first with the assistance of Fig. 4a. These explanations apply analogously to Figs. 4b and 4c.

In a housing 35, respectively 4 fiber lasers F_{HD1} through F_{HD4}, F_{VD1} through F_{VD4}, F_{HR1} through F_{HR4}, F_{VR1} through F_{VR4}, via the terminators 26 with the mounts 29 (Fig. 4a), are arranged in respectively four tracks of one beam packet H, being arranged side-by-side in a plane. The embodiment of the terminators 26 employed in Fig. 4 is described in greater detail in Fig. 9. The terminators should preferably be inserted gas-tight into the housing 35, to which end seals 36 (Fig. 4a) can be employed. Instead of the terminators shown in Figs. 4 and 4a, differently shaped terminators can also be employed, as

described in Figs. 5, 5a, 5b, 5c, 6, 6a, 7, 9, 9a, 10, 10a, 10b, 11, 11a and 12, when corresponding mounts 29 are provided in the housing 35. However, as also described under Fig. 3, single-mode fibers or other fibers 28 can be attached to the fiber lasers before the terminators 26 are attached. However, an arrangement of the laser fibers 5 or fibers 28 according to Figs. 40, 40a, 40b, 40c, 40d and 41 can also be employed. For example, the fiber lasers F_{HD1} through F_{HD4} or, respectively, F_{VR1} through F_{VR4} should have a different wavelength than the fiber lasers F_{VD1} through F_{VD4} or, respectively, F_{HR1} through F_{HR4}. For example, F_{HD1} through F_{HD4} and F_{VR1} through F_{VR4} should have a wavelength of 1100 nm whereas F_{VD1} through F_{VD4} or, respectively, F_{HR1} through F_{HR4} should have a wavelength of 1060 nm, which can be achieved by a corresponding doping of the laser-active core material of the laser fibers 5. However, all fiber lasers can also exhibit different wavelengths when they are correspondingly compiled [sic].

As explained in greater detail in Figs. 28 and 28a, the beam packets of the fiber lasers F_{HD1} through F_{HD4} are united with those of the fiber lasers F_{VD1} through F_{VD4} and the beam packets of the fiber lasers F_{VR1} through F_{VR4} are united with those of the fiber lasers F_{HR1} through F_{HR4} to form a respective beam packet F_{D1} through F_{D4} as well as F_{R1} through F_{R4} (Fig. 4a) via wavelength-dependent mirrors 37 as means for the combining. There are also other possibilities of influencing the wavelength of the fiber lasers; for example, wavelength-selecting elements such as Brewster plates, diffraction gratings or narrowband filters can be introduced in the region of the laser fibers between infeed mirror 7 and outfeed mirror 12. It is also possible to provide at least one of the two laser mirrors 7 or 12 with a mirror layer of a type that is adequately highly reflective only for the desired wavelength. The inventive execution of the beam merging, however, is not limited to the employment of fiber lasers with different wavelengths. In addition to fiber lasers that have no privileged direction in the polarization of the laser emission that is output, fiber lasers can also be employed that output polarized laser emission. When the wavelength-

dependent mirror is replaced by a mirror that is polarization-dependent such that it allows one polarization direction to pass whereas it reflects the other polarization direction, only two differently polarized laser types need be employed in order to unite the two with the polarization-dependent mirror. In this case, the employment of the terminator 26 according to Fig. 9 having a quadratic cross-section is especially suitable, since the one or the other polarization direction can be respectively produced with the same fiber laser by turning the terminator by 90° before being mounted into the housing 35.

A particular advantage of the combining of a plurality of lasers to form a single spot, namely to each of the individual processing points B_1 through B_n (for example B_1 through B_4 in Figs. 20 through 22) is that a higher power density is achieved given a predetermined spot size on the processing surface 81.

The laser emission of the individual fiber laser can also be distributed onto a plurality of terminators, this being described in Fig. 15. This is particularly useful when materials are to be processed that manage with a low laser power or when the power of an individual fiber laser is adequately high. In such a case, it is conceivable that a laser gun 23 is equipped with only four terminators, for example F_{HD1} through F_{HD4}, for this purpose, F_{HD1} and F_{HD2} thereof, for example, being supplied by one fiber laser and F_{HD3} and F_{HD4} being supplied by a further fiber laser according to Fig. 15. When the principle described in Fig. 15 is applied twice, all four tracks F_{HD1} through F_{HD4} can be supplied by one fiber laser, this leading to an extremely cost-beneficial arrangement, particularly since further component parts such as wavelength-dependent mirrors and strip mirrors can be eliminated and, thus, an especially economical embodiment of the laser radiation source can be created.

By omitting fiber lasers or, respectively, tracks, further, the acquisition costs for such an arrangement can be lowered as needed and fiber lasers can be retrofitted later as needed. For example, one can begin with one fiber laser and one track. The lacking terminators of the fiber lasers that are not introduced are replaced for this purpose by structurally identical terminators that,

however, do not contain a through opening and no laser fibers and only serve for termination in order to close the housing 35 as though it were equipped with all terminators.

However, the laser radiation of a plurality of fiber lasers can also be combined and conducted into a single terminator, this being described in Fig. 16. For example, one can work with a plurality of fiber lasers combined in this way and with one track when, as described, the missing terminators are replaced by structurally identical terminators that, however, do not contain a through opening and no laser fibers in order to close the housing 35 as though it were equipped with all terminators.

Immediately after the ray beam has left the respective terminator, a part of the laser emission can be coupled out via a beam splitter (which, however, is not shown) and can be conducted onto a measuring cell that is not shown in the Figs. in order to produce a measured quantity therefrom that can be used as comparison value for a control of the output power of each and every fiber laser. However, laser emission can also already be coupled out of the laser fiber for the acquisition of a measured quantity before the terminator, this also not being shown.

The plurality of planes wherein the terminators are arranged is not limited to the one plane as described. For example, arrangements having three planes are recited in Figs. 29, 32, 33 and 41. An arrangement having two planes is shown in Fig. 38.

The respective beam packets of the fiber lasers are modulated via a respective four-channel acousto-optical modulator 34 whose functioning and embodiment is explained in greater detail in Figs. 17, 18, 19 and 19a. Using the acousto-optical modulator 34, which is a deflector in terms of principle, the unwanted energy in the case illustrated here is deflected out of the original beam direction I_0 into the beam direction I_1 (Fig.4a), so that it can be simply intercepted later in the beam path and neutralized. The modulation can preferably ensue digitally, i.e. a distinction is made between only two

conditions in the individual modulator channels, namely "on" and "off", this being especially simple to control; however, it can also ensue analog in that the laser power in each modulator channel can be set to arbitrary values. The modulation is not limited thereto that the energy from the beam direction I_0 is employed for the processing and the energy from the direction I_1 is neutralized. Figs. 36, 36a, 36b, 36c and 37 recite examples wherein the beam direction 1_1 that is diffracted off is employed for processing and the energy from the direction I_0 is neutralized. Further, a slight part of the modulated radiant power of the individual modulator channels can be forward onto a respective measuring cell via a beam splitter (not shown) in order to generate a measured quantity that is used as comparison value in a control circuit for the exact regulation of the laser energy of each track on the processing surface.

The multi-channel acousto-optical modulator 34 is preferably secured on a cylindrical modulator housing 41 that is rotatably seated in an opening 48 in the housing 35. After the modulator housing has been adjusted to the required Bragg angle α_B, the modulator housing is fixed with a connection 42. A seal 43 sees to it that each modulator housing terminates gas-tight relative to the housing 35. A specifically prepared printed circuit board 171 projects from the modulator housing 41 into the interior space 44 of the housing 35, electrical connections to the piezo-electric transducers 45 being produced thereover. The preferred embodiment of the modulators is described in greater detail in Figs. 19 and 19a.

After passing through the acousto-optical modulators, the beam packets F_{D1} through F_{D4} and F_{R1} through F_{R4} are conducted to a strip mirror 46 that is described in greater detail in Figs. 26, 26a, 27, 27a and 27b. The beam packets F_{D1} through F_{D4} is arranged such with respect to the strip mirror 46 that it can pass through the strip mirror unimpeded. The laser beam bundles of the beam packet F_{R1} through F_{R4}, however, are offset by half a track spacing compared to the beam packet F_{D1} through F_{D4} and impinge the strips of the strip mirror arranged strip-shaped. As a result thereof, they are redirected in terms of their

direction and now lie in one plane with the laser beam bundles F_{D1} through F_{D4}. An eight-track arrangement thus derives, whereby two lasers of different wavelengths are also superimposed in each track, so that a total of sixteen lasers have been merged and take effect. Two beams I_1 that have been diffracted off in the acousto-optical modulator 34 are located above this plane I_0. Given a different adjustment of the acousto-optical modulator 34, the rays that are diffracted off can also lie under the plane of I_0, as shown in Figs. 4b and 4c.

A significant advantage of the inventive arrangement is that the symmetry axis [sic] of the beam packets F_{HD1} through F_{HD4} and F_{D1} through F_{D4} lie on the axis of the housing 35 that is defined by the bore 47, and the beam axes of the appertaining beam packets respectively lie parallel or at a right angle to this axis, which allows a simple and precise manufacture. However, it is also possible to arrange the beam packets asymmetrically and at different angles. Further, it is possible to correct small differences in the position of the beam packets by adjusting the wavelength-dependent mirrors 37 and of the [sic] strip mirror 46. It is possible to still re-adjust the terminators in position after they are mounted and in terms of their angular allocation, for example for individual optimization of the Bragg angles in the individual channels; this, however, is not shown in the Figures.

It lies within the scope of the invention that the plurality of tracks is reduced but can also be increased further; for example, by joining respectively eight instead of four terminators that are connected to fiber lasers to form a beam packet, a doubling of the number of tracks can be undertaken. To this end, two eight-channel acousto-optical modulators would have to be utilized. Acousto-optical modulators have a 128 separate channels on a crystal can be commercially obtained.

Within the framework of the invention, it is likewise possible to arrange the fiber lasers in different planes for increasing the power per track and to superimpose their power on the processing surface, this being explained in greater detail in Figs. 29, 31, 32, 33 and 41 and/or to arrange a plurality of fiber

lasers in bundles in order to superimpose their energy on the processing surface, this being described in Figs. 30 and 31.

Another possibility for increasing the number of tracks is described in Fig. 37.

Directly modulatable fiber lasers can also be utilized, this being described in greater detail in Fig. 23. In this case, the acousto-optical modulators are omitted and an especially simple structure derives.

Operation with a plurality of tracks of lasers and a plurality of lasers in a track enables high processing speeds given low relative speed between the laser gun and the workpiece. The processing speed can also thus be optimally adapted to the time constant of the heat elimination of the material. Given a longer operating time, namely, too much energy uselessly flows off into the environment.

The housing 35 is closed gas-tight with a cover and a seal, neither being shown in the Figures. A cylindrical tube 51 is flanged to the housing 35 in the region of the bore 47 and is sealed via a seal 52. The cylindrical tube contains an optical as transmission unit, namely two tubes 53 and 54 each having a respective optical imaging system that image eight laser beam bundles F_{D1} through F_{D4} and F_{R1} through F_{R4} at the beam exit 10 (Fig. 1) onto the processing surface in the correct scale. Two optical imaging systems are preferably arranged following one another, since an extremely great structural length or a very small distance between the objective lens and the processing surface would otherwise derive, both being disadvantageous since a long beam path must be folded with mirrors and too small a spacing between objective lens and processing surface could lead to a high risk of contamination for the objective lens.

The beam path is shown as a side view in Fig. 4. The fundamental beam path is shown in Fig. 20 as a plan view for the beam packet F_{HD1} through F_{HD4}. The wavelength-dependent mirrors, the modulators and the strip mirrors are not shown therein. The Figures mainly show plano-convex lenses; however, it

is also possible to utilize other lens forms such as, for example, biconvex or concave-convex lenses or lenses having an aspherical shape in all figures. Lens systems that are respectively composed of a plurality of lens combinations can also be employed.

In order to transmit the laser energy as efficiently as possible and keep the heating of the optical components within limits, all optical surfaces occurring in the various embodiments of the laser radiation source are anti-bloomed with outmost quality for the wavelength range coming into consideration. The optical imaging systems can preferably be telecentrically implemented.

There are also other advantageous solutions for the transmission unit in order to shorten the structural length of the transmission unit and thereby nonetheless achieve a large spacing between the objective lens and the processing surface, as is shown in even greater detail in, among others, Figures 4b and 4c. The lenses 55 and 56 can be connected to the tube 53 by screwed connections or by gluing; however, they can also be preferably metallized at their edges and soldered to the tube 53. The same is true of the lenses 57 and 61 in the tube 54. A gas-tight seal of the lenses and a good heat transmission from the lenses to the tubes thus derives. The tube 54 is preferably terminated gas-tight relative to the cylindrical tube 51 with a seal 62. With respect to tightness and cleanliness, the same conditions apply to the space 63 as apply to the space 44 and, likewise, to the spaces 64 and 65 within the tubes 53 and 54. The chambers 66 and 67 are preferably connected to the spaces 44 and 63 via bores 71. The tubes 53 and 54 can preferably comprise openings 72.

An intercept arrangement 73 for neutralizing the laser radiation that is not intended to produce any processing effect on the processing surface and that comprises a high-reflectivity mirror 74 and a dispersion lens (concave lens) 75 projects into the space 63. The principle of the intercept arrangement 73 is described in greater detail in Fig. 18. The intercept arrangement 73 is introduced with a seal 76, and the concave lens 75, which can also be replaced

by some other optical element, for example a glass plate, is glued into the intercept arrangement or is preferably metallized image edge zone and soldered to the intercept arrangement for better heat elimination. The space 63 is thus closed off gas-tight from the environment. What derives as a result of the described measures is that the entire interior of the laser gun is sealed gas-tight from the environment. The spaces 44, 63, 64 and 65 and the chambers 66 and 67, i.e. the entire interior of the laser gun, can be preferably evacuated or filled with a protective atmosphere. The spaces and chambers should be as free as possible of components that output gases or particles because dirt could otherwise settle on the highly stressed optical surfaces, which would lead to a premature failure of the arrangement. The demand is therefore also made of the seals to be employed that they not give off any particles or gases. Ultimate cleanliness of the parts to be assembled and of the environment has great value attached to it during assembly until the laser gun has been closed. After the closing of the laser gun 23, an evacuation of the entire interior can be undertaken via the valve 77 or a protective atmosphere can be filled in. The advantage of filling the interior with protective atmosphere is that it is simpler to replenish in that a gas bottle (not shown) is connected to the valve 77 during operation via a pressure-producing valve, gas being capable of being refilled into the housing therefrom as needed. Another advantage is that, when a terminator is to be removed from the housing for the replacement of a fiber laser and is to be replaced by another or when the housing or, respectively, the cylindrical tube must be opened by the user for some reason or other, a slight quantity of the protective atmosphere can be allowed to flow through the housing during the procedure in order to thus prevent the penetration of dirt particles into the protected space. A slight quantity of the gas can also be allowed to constantly flow through the housing and escape such through openings, preferably in the proximity of the objective lens, that this flow also prevents a contamination of the objective lens by dirt particles that are released during the processing event (Fig. 39a). The evacuation or the filling with

protective atmosphere can also be foregone when a shorter service life of the laser radiation source is accepted.

It is advantageous in the arrangement according to Fig. 4 that the angle between the beam packets of the original beam direction I_0 of the acousto-optical modulator and the beam direction I_1 that is diffracted off is noticeably increased by the imaging system composed of the lenses 55 and 56, so that it is simple to intercept the unwanted radiation packet of the deflected beam direction with the highly reflective mirror 74 at the intercept arrangement 73. The mirror 74 is preferably fabricated of metal and is provided with a highly reflective layer in order to keep the heating as a consequence of absorbed laser energy low. For better heat elimination, it is connected via a strong flange of the intercept arrangement 73 to the tube 51. However, the intercept arrangement can also be foregone when the highly reflective mirror is replaced with an optical component such as, for example, a lens that slightly modifies the optical properties of the laser radiation to be intercepted such that the focus of the radiation that is diffracted off is different from the focus of the radiation employed for processing the material. If the radiation to be intercepted would then also conducted onto the processing surface, the radiation to be intercepted would not have the required power density in order to erode material but would be uselessly absorbed and reflected. The advantage of the arrangement according to Fig. 4 is comprised therein that low demands are made of the optical components in the two tubes. The two tubes could also be implemented completely the same. Another advantage is comprised therein that the axes of the terminators 26 lie parallel to one another. The distance between the objective lens 61 and the processing surface 81 dare not be too small, so that particles that fly off from the material surface do not proceed onto the objective lens. When it is contaminated, namely, then it absorbs the laser energy that passes three and is destroyed and thus unuseable. In order to prevent the contamination, a special mouthpiece 82 is arranged between the

objective lens 61 and the processing surface 81, this being described in greater detail under Fig. 34.

The laser gun 23 of the laser radiation source is rotatable around the optical axis that is identical to the axis of the cylindrical tube 51, 95 within the arrangement for processing materials (Fig. 3), for example on a prism 83, and is seated displaceable in the direction of the optical axis and fixed in its position with a strap retainer 85 or with a plurality of strap retainers. As a result thereof, an exact delivery of the laser gun to the processing surface 81 is possible. A plate 86 that comprises openings 87 through which a coolant can be pumped is located outside the prism 83. The job of this plate 86 is to intercept and divert the laser energy intercepted from the beam path of the transmission unit, this being shown in greater detail in Fig. 18. A heat dam that, however, is not shown in the Figs., is located between the plate 86 and the tube 51, 95, 113. The plate is connected to the tube 51, 95, 113 via insulating flanges 91. The flanges 91 also prevent the emergence of laser radiation.

By turning the laser gun 23 around its optical axis, the track spacing of the laser tracks on the processing surface 81 can be modified, this being shown in greater detail in Fig. 35. It lies within the scope of the invention that the turning of the laser gun for setting the track spacing as well as the setting of its spacing from the processing surface can be implemented not only exclusively manually but with the assistance of a suitable, preferably electronic control and/or regulation. Suitable measuring devices (not shown) can also be inventively provided for this purpose, these being located in the proximity of the processing surface and being capable of being approached by the laser gun as needed. A further possibility for adjusting the track spacing is described in Figs. 36, 36a, 36b, 36c and 37. A manually or motor-adjustable vario-focusing optics can also be utilized for setting the track spacing. Such a vario-focusing optics, in addition to permanently arranged lenses, preferably has two movable lens system, whereby an adjustment of the first lens system mainly effects an adjustment of the imaging scale, with which the track spacing can be

influenced, and whereby an adjustment of the second lens system mainly effects an adjustment of the focusing. An iterative setting can be undertaken for optimizing track spacing and best focus. It is also possible to arrange a displaceable lens (not shown) having a long focal length, preferably between the lenses 57 and 61, with which the focusing of the processing points on the processing surface can be finely readjusted without having to displace the radiation source because the resultant focal length of two lenses is dependent on their spacing.

As a result of the high laser power, the optical elements in the beam path will heat, since they absorb a part, even though a slight part of the laser energy. Preferably, the critical optical components are therefore not made of glass but of a material having better thermal conductivity, for example of sapphire. The waste heat, given metallization of the connecting surfaces of the optical components, is eliminated by the solder connections to the mounts and to the housing. For better heat output, the housing is implemented with cooling ribs 92 that can be cooled by a ventilator (not shown). A permeation of the housing 35 as well as of the other component parts of the laser radiation source with bores is also possible, particularly in the critical regions at the lens mounts and mounts for the terminators 26, a coolant being capable of being pumped therethrough, as shown in Figs. 8 and 39.

Since, as presented above, extremely high laser powers are required in processing of materials, it is critical to the invention to keep the plurality of optical elements, particularly lenses, in the beam path as low as possible in order to keep the optical losses and the risk of contamination of the optics, which would always lead to a premature failure, as low as possible. It is also lies within the scope of the invention that the objective lens (61, 103 and 112) is equipped with an interchangeable mount so that it can be quickly replaced by the user of the laser radiation source as needed, whether because it has been contaminated during operation or because a different imaging scale is requested.

In this case, it is advantageous that the bore 72 and the tube 54 is not implemented.

It also lies within the scope of the invention that measures are undertaken in the optical beam path so that no laser energy can proceed back into the lasers. It is shown in Fig. 3 that the laser radiation impinges the material to be processed not perpendicularly but at an angle, so that the radiation reflected at the material surface cannot proceed back into the laser radiation source. It is also shown in Figs. 4, 4b, 4c and Fig. 18 that the laser radiation to be destroyed can be conducted by an obliquely placed concave lens 75 into a sump composed of an obliquely placed plate 86 that can be cooled. Instead of the concave lens of 75, some other optical component, for example a plate or a diaphragm, can also be inventively employed. The effective diameter of this optical component is thereby dimensioned such that the laser radiation conducted into the sump can just pass, whereas radiation that is reflected back from the sump or is dispersed back, is largely retained, so that no energy can proceed back into the laser. Inventively, the surface of the plate 86, which is shown as a planar surface in the Figures, can also be implemented crowned or hollow and can be preferably roughened in order to absorb a maximum of radiation and reflect or, respectively, disperse a minimum of radiation.

It is also shown for two planes in Fig. 8 that, as a result of a slight parallel offset of the beam axes of the ray beams emerging from the terminator, an oblique incidence onto all effected lens surfaces can be achieved. This also applies for the arrangement having one or more planes. The acousto-optical modulator 34 is already rotated by the angle α_B relative to the axis of the ray beam; however, it can also be additionally rotated by the angle γ relative to the symmetry axis of the ray beam or an arrangement according to Fig. 24 can be employed wherein the axes of the ray beams emerging from the terminators proceed at an angle relative to one another. It has been shown in practice that angular differences of 1 through 2 degrees between the perpendicular onto the

optical surface and the axis of the beam bundle are already adequate in order to achieve protection against radiation reflected back into the laser.

It lies within the scope of the invention to select embodiments of the optical, mechanical and electrical arrangement for Fig. 4 deviating from the described embodiment. For example, the radiation packets F_{D1} through F_{D4} and F_{R1} through F_{R4} could be focused onto the processing surface by a shared lens, similar to that shown in Fig. 31, which in fact yields a very high powered density but cannot present the shape of the processing spot as well since all processing points lie on one another and are united to form a common spot.

Fig. 4b shows another inventive laser gun for a laser radiation source that differs from the laser gun shown in Fig. 4 on the basis of a housing 93, terminators 94, a cylindrical tube 95, a tube 96 and on the basis of a highly reflective mirror 97.

The housing 93 has mounts 29 fitting the terminators 94. The terminators 94 preferably correspond to those of Figs. 10, 10a and 10b; the axes [...] ray beams do not proceed parallel in the appertaining beam packets. Rather somewhat toward the center of the concave lens 101, which is shown in the plan view 21. However, all other terminators according to Figs. 5, 5a, 5b, 5c; 6, 6a; 7, 9, 9a; 11, 11a and 12 can also be employed when it is seen to that the mounts 29 therefor are arranged at a corresponding angle. The transmission unit is located in the tube 96, this transmission unit being composed of three lenses, namely a dispersion lens, i.e. a concave lens 101, and two positive lenses, i.e. convex lenses 102 and 103, whereby the convex lens 103 is preferably implemented as an interchangeable objective lens. For the mounting of the lenses with respect to tightness and heat elimination, that stated under Fig. 4 and Fig. 4a applies, as it does for the selection of material with respect to the heat conduction.

The tube body 96 can be evacuated in the space between the lenses 101 and 102 or can be filled with a protective atmosphere or, preferably, be connected to the space 105 via a bore 104, said space 105 being in turn

connected via a bore 106 to the space 107. The space 107 is connected to the space 111 via the bore 47, said space 111 being in turn terminated gas-tight, as described under Fig. 4 and Fig. 4a. The space between the lenses 102 and 103 can be connected via a bore (not shown) to the space 105, particularly when the mount of the objective is closed gas-tight or, as described under Fig. 4, when a slight amount of the protective atmosphere constantly flows through the laser gun and emerges in the proximity of the objective lens, this, however, not being shown in Fig. 4b. The entire interior of the laser gun, composed of the spaces 111, 105, 107, is preferably evacuated or filled with a protective atmosphere or, respectively, flooded by a protective atmosphere, as was described in detail under Fig. 4 and Fig. 4a. The undesired ray beams are intercepted with a highly reflective mirror 96; in contrast to Fig. 4, however, no lens system is present that has an angle-enlarging effect, so that the distance between the highly reflective mirror and the modulators is kept correspondingly large here in order to achieve an adequate spatial separation of the beam packets I_0 and I_1. Nonetheless, the entire structural length of the laser gun is similar here to the arrangement of Fig. 4. The optical beam path of the transmission unit in Fig. 4 represents a side view. Fig. 21 indicates a fundamental beam path for a plan view relating to Fig. 4b. The beam path of the lenses 101 and 102 corresponds to that of an inverted Galileo telescope; however, it can also be implemented as an inverted Kepler telescope when the concave lens 101 having a short focal length is replaced by a convex lens. Such telescopes are described in the textbook "Optik" by Klein and Furtak, Springer 1988, pages 140 through 141. The advantage of the arrangement according to Fig. 4b is that only three lenses are required for the transmission unit. The disadvantage, to wit that the ray beams of the individual terminators do not proceed parallel, is eliminated by terminators according to Figs. 10, 10a and 10b.

A lens 55 could also be employed in order to deflect the ray bundles into the desired direction, as was shown in Fig. 20. The individual laser ray

bundles would then proceed parallel to one another between the terminators 26 and the lens 55, that is arranged as in Fig. 4, and no difference from Fig. 4 derives with respect to the housing and the terminators or, respectively, their arrangement. Since, however, the lens 55 also exercises a collecting effect on the individual ray bundles in addition to the deflecting effect, the same conditions as in Fig. 21 would not arise at the location of the concave lens 101. This, however, can be compensated by a different adjustment of the spacing of the fiber 28 or, respectively, of the laser fiber 5 from the lens 133 or by a modification of the lens 133 in the terminators 26, i.e. the ray cone of the laser ray bundle from the individual terminators would be respectively set such that a sharp image respectively derives on the processing surface at the location of the points B_1 through B_n.

According to the invention, it is also possible to combine the lenses 102 and 103 to form a single, shared lens. A transmission unit having only two lenses then derives. It is also possible to arrange a displaceable lens (not shown) with a long focal length between the lenses 101 and 102, the focusing of the processing points on the processing surface being capable of being finely readjusted therewith without displacing the radiation source. A vario-focusing optics can also be employed, as was mentioned under Fig. 4.

A special mouthpiece 82 is provided at the laser gun 23 that is intended to prevent a contamination of the objective lens 112 and that is described in greater detail under Fig. 34.

Fig. 4c shows a laser gun that is even more significantly compactly implemented than that of Fig. 4 and Fig. 4a. In combination with a mirror arrangement, an objective lens 112 is employed as transmission unit and this can be interchanged for achieving different imaging scales. As already described under Fig. 4, a vario-focusing optics can also be employed. Inventively, however, an imaging can ensue with the mirror arrangement by itself without additional objective lens 112.

Fig. 4c differs form Fig. 4b in terms of the following points:

The cylindrical tube 95 is replaced by an eccentric tube 113. The tube body 96 is preferably replaced by a plate 114 having a concave mirror 115 and a mount 116 with an objective lens 112 and a highly anti-bloomed plate 117. The intercept unit 73 is given an arced (convex) mirror 121 above the highly reflective mirror 97. The eccentric tube is connected to the housing 93 at one side. A seal 52 sees to the required tightness. The plate 114 is introduced into the eccentric tube 113, said plate 114 containing a passage for the beam packets I_0 and I_1 and carrying the concave mirror 115 whose dissipated heat can thus be diverted well to the eccentric tube. The eccentric tube has two axes that are preferably parallel to one another, namely, first the symmetry axis of the entering beam packets having the direction I_0 that are directed onto the arced mirror and, second, the axis between concave mirror and objective lens 112 that can be considered as an optical symmetry axis for the emerging laser radiation.

Inventively, the beam path is folded with the two mirrors 121 and 115. The arced mirror 121 is preferably fabricated of metal. It is intimately connected to the highly reflective mirror 97 and is preferably fabricated of one piece therewith. The convex surface of the arced mirror can be spherically or aspherically shaped. The mirror 115 is concavely shaped, i.e. a concave mirror. Its surface can be spherically shaped but is preferably aspherically shaped. It is preferably composed of metal. Metal has the advantage of good elimination of the waste heat. A considerable advantage given manufacture of metal also derives in the production of aspherical surfaces, which, in this case, can be produced by known diamond polishing lathing methods, as can also spherical and planar surfaces. As a result thereof, the highly reflected mirror 97 and the arc mirror 121 can be manufactured of one piece and, preferably, in one work pass having the same shape of the surface and can be mirrored in common, which is particularly simple in terms of manufacture and very advantageous for the positional stability of the arced mirror. In the modulation of the laser energy with the acousto-optical modulator, it impinges either the arc mirror 121 or the highly reflective mirror 97. The waste heat that is produced remains

the same in any case and the arced mirror stays at its temperature and, thus, its position, which is very important since it is preferably implemented with a short focal length and the imaging quality of the arrangement is therefore very dependent on its exact position. In this case, the arced mirror 121 has advantageously co-assumed the function of the highly reflected mirror 97. The highly reflective mirror can 97 [sic], however, also have some other form of the surface than the arced mirror 121 and, for example, can be a plane mirror.

The beam path is similar to that of an inverted mirror telescope of Herschel that, however, contains a convex lens instead of the arced mirror and that is described in greater detail in Fig. 22. Mirror telescopes are described on page 152 in the "Lehrbuch der Experimentalphysik Band III, Optik" by Bergmann-Schäfer, 7th edition De Gruyter 1978. The arced mirror can also be replaced by a concave mirror having a short focal length. As a result thereof, the structural length would be slightly enlarged and different ray cones of the ray bundles emerging from the terminator would have to be set in order to obtain a sharp image in the image plane. The arced mirror could also be replaced by a convex lens having a short focal length. Another folded mirror would then have to be utilized in order to preserve the compact structure. The intercept arrangements 73 is attached gas-tight to the eccentric tube via a seal 76 the undesired laser energy, as described under Figs. 4, 4b and 18, being diverted via said intercept arrangement 73 to a cooling plate 86 with bores 87 and being neutralized. It is also possible to already intercept the undesired laser radiation from the beam packet I_1 at the location of plate 114 and neutralize it.

The space 111 in the housing 93 is connected to the cavity 123 via the bore 122. Both spaces can be evacuated or, preferably, be filled with a protective atmosphere or, respectively, flooded by a protective atmosphere, as already described. The mount 116 that accepts the interchangeable objective lens 112 is attached to the end of the eccentric tube 113 that resides opposite the housing 93. A seal 124 closes the cavity 123 gas-tight. The mount can also accept an anti-bloomed plate 117 whose edge is preferably metallized and that is

preferably soldered gas-tight to the mount. Its job is to keep the cavity 123 gas-tight when the objective lens was removed for cleaning or when an objective lens having a different focal length is to be introduced in order to generate a different imaging scale. The space between the objective lens 112 and the highly anti-bloomed plate 117 can also be connected to the space 123 via bore (not shown), particularly when the entire laser gun, as described under Fig. 4, constantly has a protective atmosphere flowing through it, this emerging in the proximity of the objective lens 112, which is shown in Fig. 39a. The highly anti-bloom plate 117, however, can also contain optical correction functions, as known for the Schmidt optics known from the literature, in order to thus improve the optical imaging quality of the arrangement. However, it is also possible to omit the highly anti-bloom plate, particularly when it contains no optical correction function and the objective lens was introduced gas-tight or a protective atmosphere flowing therethrough sees to it that no dirt can enter into the space 123 when the objective lens is replaced. A special mouthpiece 82 is provided at the laser gun 23, this being intended to prevent a contamination of the objective lens 112 and being described in greater detail under Fig. 34.

The eccentric tube can be provided with cooling ribs 92 over which a ventilator (not shown) can blow in order to eliminate the waste heat to the environment better. The laser gun is rotatably seated in a prism around the axis between concave mirror and objective lens in order, as described under Fig. 4, to make the track spacing adjustable and in order to set the correct distance from the processing surface 81. The laser gun can be fixed with a strap retainer 85.

It is possible to arrange a displaceable lens (not shown) having a long focal length between, preferably, the concave mirror 115 and the objective lens 112, the focusing of the processing points onto the processing surface being capable of being finely readjusted therewith without displacing the laser gun. However, a variable focusing optics can also be utilized, as was described under

Fig. 4. All descriptions that were provided for Figs. 4, 4a and 4b also apply analogously.

Fig. 5 shows a preferred embodiment of a terminator 26 for a fiber 28 or laser fiber 5, which is also a fiber. Plug-type connections for optical fibers for low powers are known in optical communications technology, in sensor applications and mensuration technology; these, however, are not suitable for high powers because too much heating occurs, this leading to destruction. For example, such laser diode collimator systems, beam shaping optics and coupling optics are described in the catalog 1/97 of Schäfter & Kirchhoff, Celsiusweg 15, 22761 Hamburg, pages A1 through A6. However, the power of these systems is limited to 1000 mW and is thus below the demands for the desired applications in processing materials by the factor of 100 because an adequate heat elimination is not assured. Further, these systems are relatively large in diameter, so that no high packing density of the laser outputs can be achieved. Another great disadvantage is comprised therein that these systems are not adequately sealed; they would get dirty very quickly and burn up due to an increased absorption of the laser radiation. Last but not least, it should also be mentioned that the precision of the mount for fibers and the lens are [sic] inadequate for the desired application. Terminators according to this patent application are therefore significantly more advantageous. Such terminators can be advantageously employed for coupling laser radiation out of a fiber 5, 28, as disclosed in the German Patent Application P 198 40 935.4 of the assignee "Abschlussstück für Lichtleitfasern".

This terminator 26 can be fundamentally used for all applications wherein the matter of concern is that the ray bundle emerging from a fiber 5, 28 be precisely coupled with a releasable connection. It is likewise possible with the assistance of this terminator to produce a precise, releasable connection of the fiber 5, 28 to the remaining optics. The terminator is composed of an oblong housing 132 that comprises a through cylindrical opening 130 extending in axial direction. The housing is preferably

manufactured of prefabricated, for example drawn material that can preferably be composed of glass. The laser fiber 5 of the fiber laser is preferably stripped of its cladding at its ultimate end and is preferably roughened at its outside surface, this being disclosed in German Patent Application P 197 23 267, so that the remaining pump radiation leaves the laser fiber before the entry of the laser fiber into the terminator. The fiber 5, 28 can also be additionally surrounded by a single-layer or multi-layer protective sheath 131 that can be connected to the housing 132 of the terminator, for example with a glued connection 142. The housing 132 comprises fits 134 with which the housing can be exactly introduced in a mount 29 (Fig. 5a, Fig. 7, Fig. 8, Fig. 14). The fits can thereby extend over the entire length of the housing (Figs. 5b, 9, 10); however, it can also be attached in limited regions of the housing (Figs. 5, 6, 7). One or more seals 36 can be provided that, for example, are connected to the housing 132 with glue connections 142. The job of the seals is to enable a gas-tight connection of the terminators to the mounts 29. The housing can have a different diameter, for example a smaller diameter, in the region of the protective cladding 131 and of the seal 36 than in the region of the fits. At the end of the housing 132, the end of the fiber 28 or, respectively, of the laser fiber 5 is accepted and conducted within the housing in the opening 130. A lens 133 having a short focal length is secured to the other end of the housing 132, whereby the housing can comprises a conical expansion 139 so as not to impeded the laser radiation 13. Means can be provided for adjusting the position of the fiber 5, 28 within the terminator in order to adjust the position of the fiber relative to the lens 133 within the terminator and with reference to the fits 134, as shown in Figs. 5b, 5c, 6, 6a, 7, 9, 9a, 10a, 10b, 11, 11a and 12. The radial position of the fiber 5, 28 can also be defined by the cylindrical opening 130, whereby the fiber is axially displaceable within the opening. The position of the lens 133 can either be adequately precisely mounted during assembly or can be axially and/or radially adjusted and fixed with suitable means (not shown) with reference to the fiber 5, 28 and to the fits 134, whereby

the fiber can also be axially displaced (Fig. 5b). The adjustments are advantageously undertaken with a measuring and adjustment device. What the adjustment is intended to achieve is that the ray bundle 144 emerging from the lens 133 is brought into a predetermined axial and focus position with a defined cone relative to the fits 134. After a fixing of the fiber 5, 28 within the housing 132 and of the lens 133 at the housing, the measuring and adjustment device is removed. Inventively, it is also possible to provide the end of the fiber 5, 28 with a suitable coating, for example a correspondingly thickly applied metallization 141, in the region of the terminator before assembly in order to further improve the durability of the adjustment. The fixing of the fiber 5, 28 within the housing 132 can ensue with suitable means such as gluing, soldering or welding. An elastic compound 138 that represents an additional protection for the fiber is preferably provided at the transition between the housing 132 and the protective sheath 131. It is also inventively possible to fashion and align the lens 133 by corresponding shaping and vapor-deposition of a corresponding layer, preferably at its side facing toward the fiber end, such that it co-assumes the function of the outfeed mirror 12 for the fiber laser.

Fig. 5a shows a multiple arrangement of fiber laser outputs with the terminators from Fig. 5. Bores 150 for the acceptance of two terminators 26 for two tracks are provided in a housing 145. Further, respectively three pins 148 and 149 are attached in rows such within the housing 145 in extension of the bores that they represent a lateral limitation as mount 29 for the terminators and see to a precise guidance and alignment of the terminators. The diameters of the pins 148 are referenced d_1 and are preferably identical to one another. The diameters of the pins 149 are referenced d_2 and are preferably likewise identical to one another. If the diameters of the pins 148 were the same as the diameters of the pins 149, the axes of the ray beams of both tracks would lie parallel to one another in the plane of the drawing since the terminators 26 comprise cylindrical fits 134. In Fig. 5a, however, the diameters of the pins 149 are shown larger than the diameters of the pins 148, this leading thereto that

the axes of the two ray beams proceed at an angle relative to one another in the plane of the drawing. The angle between the ray beams is dependent on the diameter difference d_2 - d_1 and on the center-to-center spacing m of the two pin rows. The terminators are conducted through the housing 145 at the underside in one plane and are conducted from above through a cover (not shown) of the housing that is secured to the housing and can close it gas-tight with a seal (not shown). The housing 145 can be part of a receptacle for an optical unit for shaping the laser radiation. The terminators are secured to the housing 145 with clips 147 and screws (not shown), whereby the seals 36 see to a gas-tight closure. The arrangement is not limited to two tracks; further bores 150 can be provided and further pins 148 and 149 can be introduced in order to insert further terminators for further tracks. The arrangement is not limited to the one plane as described; further bores 150 can be inserted into the housing 145 in further tracks and in one or more further planes, these lying above or below the plane of the drawing, and the pins 148 and 149 are lengthened to such an extent that they represent mounts 29 for all tracks and all planes. Inventively, pins 148 and 149 are likewise employed for producing a defined spacing between the planes. In this case, the pins proceed horizontally between the terminators. For example, the horizontally arranged pins 149 proceed between the wall of the housing 145 wherein the bores 150 lie and the row of illustrated, vertically arranged pins 149. The horizontally arranged pins 148 preferably proceed at a spacing m parallel to the horizontally arranged pins 149. Horizontally arranged pins are not shown in Fig. 2a. The pins 148, 149 are preferably fabricated of drawn steel wire; however, they can also be composed of other materials, for example of drawn glass. An advantage given the arrangement with a plurality of tracks and/or planes in the illustrated way is that the rods [sic] 148, 149 exhibit a certain flexibility. As a result thereof, it is possible to press the entire packet of the terminators together in the direction of the tracks and in the direction of the planes such that the terminators 26

with their fits 134 lie against the pins without spacing, this being desirable for achieving utmost precision.

Fig. 5b shows a terminator 26, whereby means for adjusting the position of the fiber 5, 28 within the terminator are provided in order to be able to adjust the position of the fiber 5, 28 relative to the lens 133 within the terminator and with respect to the fits 134. The position of the lens can also be adjusted. The adjustments are advantageously undertaken with an adjustment device. Adjustment screws 135, 136 (Figs. 5b, 5c, 9, 9a, 10a, 10b, 11, 11a, 12) and/or or [sic] balls 137 (Figs. 6, 6a, 7) can be provided for the adjustment of the position of the fiber 5, 28 in the housing 132. The fiber 28 or, respectively, laser fiber 5 can also be axially displaced within the adjustment screws 135, 136 or balls 137. The position of the lens 133 can either be adequately precisely mounted during assembly or axially and/or radially adjusted and fixed by means (not shown) with reference to the fiber 5, 28 and with reference to the fits 134, whereby the fiber can also be axially displaced. The adjustments are advantageously undertaken with a measuring and adjustment device. What the adjustment is intended to achieve is that the ray bundle 144 emerging from the lens 133 is brought into a predetermined axial and focus position with a defined cone on the basis of a relative advance of lens 133 and fiber 5, 28 toward the fits 134. After a fixing of the fiber 5, 28 within the housing 132 and of the lens 133 to the housing, the measuring and adjustment device is removed. That stated under Fig. 5 for this and the other embodiments continues to apply, for example regarding the metallization 141, the elastic compound 138 and the employment of the lens 133 as laser mirror.

Fig. 5c shows a cross-section through the terminator 26 in the region of the adjustment screws, from which it can be seen that preferably three adjustment screws 135 are provided distributed over the circumference, the fiber 28 or, respectively, the laser fiber 5 being adjustable in fine fashion in the housing therewith. Further, further adjustment screws 136, as shown in Fig. 5b, can be provided within the terminator at the end of the terminator at which

the fiber 28 or, respectively, the laser fiber 5 enters. These adjustment screws are fashioned like the adjustment screws 135. When only one set of adjustment screws 135 is employed, the fiber 28 or, respectively, the laser fiber 5 can only be adjusted with respect to the angle. When two sets of adjustment screws are employed, they can also be displaced parallel to their axis. The fixing of the fiber 5, 28 within the housing 132 can ensue with suitable means such as gluing, soldering or welding.

Fig. 6 shows an embodiment of the terminator 26 wherein small balls 137 of metal or, preferably, metallized glass are employed instead of adjustment screws, these being brought into their position in the housing and being subsequently glued or soldered. A plurality of sets of balls can also be applied.

Fig. 6a shows a cross-section through the terminator in the region of the balls 137.

In order to prevent the optical surfaces on the optical fiber and the side of the lens 133 that faces toward the optical fiber from contaminating biparticles in the ambient air, the connections in Figs. 5, 5b, 5c, 6, 6a, 7, 9, 10, 11, 11a and 12 between the lens 133 and the housing 132 as well as between the adjustment screws 135 and 136 or, respectively, the balls 37 and the housing 132 can be hermetically closed. This can ensue with suitable glued or soldered connections 142. When a soldered connection is preferred, the glass parts are previously metallized at the corresponding locations 141. In order to achieve a greater strength, the glued or soldered connections can also entirely or partially fill the remaining gap between the fiber 28 or, respectively, the laser fiber 5 and the housing 132 or, respectively, the protective sheath 131 in the proximity of the terminator, this being shown, by way of example, in Fig. 5. It is also possible to durably evacuate the interior 143 of the housing or fill it with a protective atmosphere.

Fig. 7 shows a further embodiment of a terminator 26 that is introduced in a housing 145 with a mount 29. Given this embodiment, the front, outer fit 134 in the region of the lens 133 is conically implemented for better sealing and

for better heat elimination. Additionally, a seal 146 can be provided that instead of being attached to the lens-side end of the terminator as shown, can also be attached to the fiber-side end thereof.

Fig. 8 shows mounts 29 in a housing 145 for a plurality of conically implemented terminators 26 according to Fig. 7. Such mounts are advantageous when a plurality of outputs of fibers or, respectively, fiber lasers are to be arranged next to one another or next to one another and above one another. The axes of the mounts can thereby be arranged such that the axes of the ray beams emerging from the terminators of the terminators lying side-by-side and/or above one another proceed parallel to one another or at an angle. In order to eliminate the waste heat, the housing 145 can be inventively provided with bores through which a coolant is conducted.

Fig. 8a shows the rear fastening of the terminators 26 in the housing 145. For fixing the terminators 26, 94, clips 147 are provided that fix the ends of the terminators with screws 151 in the housing at the locations at which the fibers respectively enter into the housing of the terminators 26, 94.

Fig. 9 shows an embodiment of a terminator 26 having a quadratic or rectangular cross-section, whereby all outside surfaces lying opposite one another proceed parallel and can be fits 134. Fig. 9a shows a cross-section through the end piece [sic] 26 according to Fig. 9 having a quadratic cross-section.

Fig. 10 shows an embodiment of the terminator 94 with rectangular cross-section, whereby two outside surfaces lying opposite one another proceed trapezoidally and two outside surfaces lying opposite one another proceed parallel to one another. The outside surfaces can be fits 134.

Fig. 10a shows a longitudinal section and Fig. 10b a cross-section through the terminator according to Fig. 10.

Fig. 11 shows terminators 26 having trapezoidal cross-sections, so that a row of terminators arises by successive turning of the terminators by 180°

when a plurality of terminators are joined to one another, whereby the center points of the terminators lie on a central line. When desired, a plurality of such rows can be arranged above one another, which is indicated with broken lines in Fig. 11.

Fig. 11a shows terminators 26 with a triangular cross-section that can likewise be arranged in a plurality of rows above one another, this being indicated with broken lines.

Fig. 12 shows terminators 26 having a hexagonal cross-section that can be arranged honeycomb-like for increasing the packing density.

The inventive terminators advantageously enable the laser radiation source to be built of individual modules.

Fig. 13 shows an applied example of the terminator 26 or, respectively, 94 given a fiber 28 or, respectively, a laser fiber 5 that have both ends provided with a respective, inventive terminator.

According to the invention, it is possible to preferably implement the lens 133 at its side facing toward the fiber end on the basis of a corresponding shape being and vapor-deposition of a corresponding layer such that it co-assumes the function of the outfeed mirror 12. According to the invention, it is also possible to implement the lens 3, 154 by corresponding shaping and vapor-deposition of a corresponding layer that it co-assumes the function of the infeed mirror 7.

It is fundamentally possible to combine a plurality of the terminators described above in a plurality of tracks side-by-side and above one another in a plurality of planes to form a packet.

It is also possible to implement the shape of the terminators differently from that shown in the Figures, for example that a cylindrical shape according to Fig. 6 is lent trapezoidal or rectangular fits according to Fig. 9 or Fig. 10.

Fig. 14 shows a coupling of the laser fiber 5 to a pump source with the terminator 26 via the housing 152 in which the pump source 18 is accommodated in a recess 153, preferably gas-tight. A seal 146 assures that the

terminal 26 likewise terminates gas-tight, so that no dirt particles can penetrate into the recess from the outside and, as needed, it can be evacuated or filled with a protective atmosphere. A constant current of a protective atmosphere can also flow through the recess 153, particularly given temporary removal of the terminator 26. The radiation of the pump source 18 is focused onto the pump cross-section of the laser fiber 5 via a lens 154. The pump source can be composed of one or more laser diodes; however, it can also be composed of an arrangement of one or more lasers, particularly fiber lasers as well, whose output radiation was united such with suitable means that a suitable pump spot arises.

Fig. 15 shows the branching of the output radiation from the laser fiber 5 of a fiber laser with a fused fiber coupler 155. Such fused fiber couplers are described for single-mode fibers on Page G16 of the catalog of Spindler and Hoyer specified in greater detail under Fig. 20 and can be directly fused to the output of the laser fiber 5 after correspondingly precise alignment. In this case, thus, the terminator 26, 94 is connected to a passive single-mode fiber or, respectively, to a different fiber 28 and not directly to a fiber laser with the active laser fiber 5. There are also other possibilities of splitting the laser beam into a plurality of sub-beams such as, for example, beam splitter mirrors or holographic beam splitters. The advantage of the described fused fiber coupler, however, is that the laser radiation can be brought to the processing point guided within fibers insofar as possible, this leading to a considerable simplification of the arrangement.

Fig. 16 shows the uniting of the radiation from the laser fibers 5 of two fiber lasers via a fused fiber coupler 156. The cross-sections of the two input fibers are united to form one fiber in the fused fiber coupler 156. For example, the diameter of the fibers at the two inputs of the fused fiber coupler amounts to 6 μm and the core diameter of the two laser fibers to be fused on likewise amounts to 6 μm. A core diameter of the single-mode fiber at the output of the fused fiber coupler thus becomes 9 μm, which still allows a faultless guidance of

a single mode for the appertaining wavelength. The diameter at the output of the fused fiber coupler, however, can also be greater than 9 μm, and more than two outputs of fiber lasers or, respectively, fibers can be united. The terminator 26, 94 in this case is thus connected to a passive single-mode fiber or other passive fiber 28 and not to a fiber laser with the active laser fiber 5.

However, all other types of light waveguides can be welded to the fiber laser or coupled thereto in some other way, for example via optics.

One or more passive single-mode fibers or, respectively, one or more other passive fibers 28 can also be coupled to an individual fiber laser instead of a brancher according to Fig. 15 or a combiner according to Fig. 16, being coupled via optics in order to then connect the terminator to this single-mode fiber or, respectively, other fiber.

However, it is also possible to unite the outputs of a plurality of fiber lasers or single-mode fibers or other suitable fibers into which laser radiation can be coupled via wavelength-dependent or polarized beam combiners or other suitable measures, and to in turn couple into single-mode fibers or other fibers that can be provided with a respective, corresponding terminator at one or both ends.

The described possibilities of branching and uniting fibers can be particularly advantageously employed when the inventive modular structure is applied to the laser radiation source.

Fig. 17 shows the principle of an acousto-optical deflector. A piezo-electric transducer 45 is applied on a substrate 161 that is also referred to as crystal, said piezo-electric transducer 45 being supplied with electrical energy from a high-frequency source 162. The laser beam 163 incident at a Bragg angle α_B is deflected out of its direction proportionably to the frequency of the high-frequency source by interaction with the ultrasound field 164 within the crystal. When the beam that is not deflected and that passes through the modulator at the moment is referenced I_0 (beam of the zero order), then the frequency f_1 yields a direction I_{11} (first beam of the first order), and the

frequency f_2 yields a direction I_{12} (second beam of the first order). Both frequencies can also be simultaneously adjacent and the beams I_{11} and I_{12} arise simultaneously, these being capable of being modulated by varying the amplitudes of the high-frequency sources. An optimum transmission efficiency for the infed radiation respectively derives when the Bragg angle amounts to half the angle between the direction of the ray beam I_0 and the direction of the deflected ray beam. For use as acousto-optical modulator, only one of the sub-beams is used. It is mostly effective for processing materials to employ the beam of the zero order because it has the higher power. However, it is also possible to use one or more beams of the first order. The energy of the beams that is not used is neutralized in that, for example, it is converted into heat on a cooling surface. Only one piezo-electric transducer 45 is provided in Fig. 17, for which reason only one laser beam 163 can be deflected or, respectively, modulated. However, a plurality of piezo-electric transducers can also be attached on the same substrate in order to thus simultaneously provide a plurality of laser beams, i.e. a plurality of channels, with different deflection or, respectively, modulation signals. The individual channels are referenced T_1 through T_n. When, as shown in Fig. 17, the acousto-optical modulator is placed into a focal point of the lens 165 and the beam path is implemented nearly parallel through the acousto-optical modulator, the beams in the other focal point of the lens 165 are focused on the processing surface arranged here, and the beam axes between the lens 165 and the processing surface 81 proceed parallel and impinge the processing surface perpendicularly. Such an arrangement is called telocentric; the advantage is that the spacing between the beam axes remains constant when the position of the processing surface changes. This is of great significance for a precise processing of material.

Fig. 18 shows how the unused beam is neutralized. The unused beam is intercepted and deflected via a highly reflective mirror 166, which is preferably manufactured of metal for better heat elimination, is dispersed by a concave lens 75 and is directed onto an obliquely arranged plate 86 having bores 87 such

that no energy can be reflected back into the laser. The plate 86 and, potentially, the mirror 166 are also cooled via a cooling system that is operated by a pump 167. It is also possible to utilize a convex lens of a glass plate instead of the concave lens. The latter particularly when a dispersion of the ray beam to be neutralized can be undertaken with other measures, which can ensue, for example, by special shaping of the highly reflective mirror 166, as described under Fig. 4c. The concave lens 75 can also be omitted when one foregoes the advantage of the complete sealing of the laser gun. The plate 86 is shown with a planar surface at an angle. A plate having an arc or a cavity can also be employed. The surface can be roughened in order to absorb the laser energy well and conducted to the coolant.

It is advantageous for an arrangement having a plurality of tracks to arrange a plurality of such modulators on a common crystal 34 according to Figs. 19 and 19a. The individual modulators cannot be arranged arbitrarily close to one another because of too much heating. A modulator of Crystal Technology Incorporated, Palo Alto, USA, is especially suited for the inventive arrangement, this being distributed under the designation MC 80 and containing five separate deflection or, respectively, modulator channels. In this case, the spacing of the channels is predetermined at 2.5 mm, whereby the beam diameter is recited as 0.6 mm through 0.8 mm. A similar product by the same company is equipped with ten channels having a spacing of 2.5 mm. The spacing of the channels of 2.5 mm requires the diameter or, respectively, the edge length of the terminators 26, 94 is implemented smaller than 2.5 mm. When the terminator 26, 94, however, is greater in diameter or, respectively, in edge length than the spacing of the channels in acousto-optical deflector or modulator, an adaptation can be undertaken with an intermediate imaging, as shown in Fig. 25. Such a multi-channel deflector or, respectively, modulator can also be employed in the exemplary embodiments according to Figs. 4, 4a, 4b, 4c, 36, 36a and 37. Dependent on the requirement of the application, all

channels need not be used. Only four channels are shown in the illustrated applied examples.

Instead of the acousto-optical modulator, however, it is also possible to utilize other modulators, for example what are referred to as electro-optical modulators. Electro-optical modulators are described under the terms "laser modulators", "phase modulators" and "Pockels cells" on pages F16 through F33 of the overall catalog G3, Order No. 650020 of Laser Spindler & Hoyer, Göttingen. Multi-channel electro-optical modulators have also been possibly employed, which is shown in the publication "Der Laser in der Druckindustries" by Werner Hülsbuch, Verlag W. Hülsbusch, Constance, page 523, Fig. 8-90a. When a one-channel or multi-channel electro-optical modulator is employed in combination with a birefringent material, then each laser beam can be split into two beams that can be separately modulated via further modulators. Such an arrangement is also referred to as electro-optical deflector in the literature.

Fig. 18a shows an arrangement having an electro-optical modulator 168. In an electro-optical modulator, for example, the polarization direction of the laser radiation that is not wanted for processing is separated from the incident ray beam 163, turned (P_b) and, subsequently, the laser radiation P_b not wanted for the processing is separated off in a polarization-dependent beam splitter, which is also referred to as polarization-dependent mirror 169, and is conducted into a sump, for example into a heat exchanger that can be composed of a cooled plate 86. The radiation P_a wanted for processing is not turned in terms of polarization direction and is supplied to the processing surface via the lens 165. In the exemplary embodiments according to Figs. 4, 4b and 4c, the single-channel or multi-channel acousto-optical modulators 34 can be replaced by corresponding, single-channel or multi-channel electro-optical modulators. In the exemplary embodiments according to Figs. 4, 4b and 4c, the highly reflective mirror 74, 97 can likewise be replaced by the polarization-dependent mirror 169 (Fig. 18a), wherefrom an intercept arrangement 78 derives, and

whereby the polarization-dependent mirror extends into the beam path wanted for the processing.

The fiber laser can also be directly modulated. Such directly modulatable fiber lasers that have a separate modulation input available to them are offered, for example, by IPG Laser GmbH D-57299 Burbach, under the designation "Modell YPLM Series". The advantage is that the acousto-optical modulators and the appertaining electronics for the high-frequency sources can be omitted. Moreover, the transmission unit can be simplified, as shown in Fig. 23.

Fig. 19 shows a plan view onto an acousto-optical deflector or, respectively, modulator. It is mentioned in the description of Figs. 4, 4b and 4c that the space 44 or, respectively, 111 according to Figs. 4, 4b and 4c wherein the modulators are arranged should be optimally free of those components that give off particles or gases because particles could thus settle onto the highly stressed optical surfaces, which would lead to the premature failure of the arrangement. For this reason, the electrical components of the arrangement in Figs. 19 and 19a are arranged on a separate printed circuit board 171 that merely has two arms projecting into the sealed space and produces the electrical connections to the piezo-electrical sensors 45. The printed circuit board 171 is sealed relative to the modulator housing 172, preferably with a solder location 173. The end face of the printed circuit board is preferably sealed by a metal band (not shown) that is soldered on in the region of the space 44 or, respectively, 111. The printed circuit board is implemented multi-layer in order to shield the individual high-frequency channels by interposed connections to ground. Instead of a printed circuit board, some other line arrangement can also be utilized. For example, each radio frequency channel can be connected by its own shielded line. The modulator housing 172 contains an access opening 174 to the electrical components. The modulator crystal 34 can be metallized at its base area and is preferably secured on the modulator housing with a solder point or a glued connection 175. A

connection 176 to a cooling system can be located directly under the fastening location in order to carry the waste heat off via the openings 87 with a coolant. The modulator housing 172 is preferably closed by a cover 177 that carries the electrical terminals 181 and also contains the connections for the cooling system, but this is not shown. A seal 43 sees to it that the modulator housing 172 is inserted gas-tight into the housing 35 or, respectively, 93 of Figs. 4, 4a, 4b and 4c and is secured with the connection 42.

It is possible to secure the electro-optical modulator 168 to the modulator housing (172) in a similar way and to contact it via the printed circuit board 171.

Fig. 20 indicates that the basic beam path for the exemplary embodiment of Fig. 4 for the ray beams 144 of the appertaining fiber lasers F_{HD1} through F_{HD4}. The ray beams of the fiber lasers F_{VD1} through F_{VD4} proceed partially congruently with the indicated rays but, inventively, have a different wavelength and, as can be seen from Fig. 4a, are united via a wavelength-dependent mirror 37 (not shown in Fig. 20) with the beam packet F_{HD1} through F_{HD4} to form the beam packet F_{D1} through F_{D4}. Further, Fig. 20 does not show the beam packets of the fiber lasers F_{VR1} through F_{VR4} and F_{HR1} through F_{HR4} that, as can be seen from Fig. 4a, are likewise combined via a wavelength-dependent mirror to form the beam packet F_{R1} through F_{R4}. As can be seen from the arrangement of the strip mirror 46 in Fig. 4a, the ray beams of the beam packet F_{R1} through F_{R4} in Fig. 20 would proceed offset by half a track spacing from the indicated rays. Instead of containing the indicated four ray beams, thus, the complete beam path contains a total of eight ray beams that yield a total of eight separate tracks on the processing surface. Fig. 20 only shows the two ray beams 144 of the fiber lasers F F_{HD1} and F_{HD4}. As already mentioned under Fig. 4, however, a plurality of tracks can also be arranged; for example, the plurality of tracks on the processing surface can also be increased to sixteen separately modulatable tracks. On the basis of a digital modulation of the respective laser, i.e. the laser is operated in only two conditions as a result

turn-on and turn-off, this arrangement enables an especially simple control and a good shaping of the processing spot on the processing surface. This digital type of modulation requires only one especially simple modulation system.

A distinction between more than 100 tonal value levels is required in high-grade multi-color printing in order to obtain adequately smooth color progressions; more than 400 tonal value stages would be optimum. When, for example, a cup in rotogravure wherein the volume of the cups determines the amount of ink applied onto the material being printed is composed of 8 x 8 or 16 x 16 small individual cups and the cup depth is kept constant, the processed surface can be quantitized into 64 or, respectively, 256 stages. When, however, the cup depth is controlled by additional, analog or digital amplitude modulation or by a pulse-duration modulation of the laser energy, the volume of the cups can be arbitrarily finely quantized even given a low plurality of tracks. If, for example, the cup depth were digitally controlled in only two stages, as described in greater detail under Fig. 28, a cup could composed of 8 x 8 individual cups given eight tracks, these potentially having respectively two different depths. I.e. the volume of the cups in this case could be quantized in 128 stages without losing the advantage of purely digital modulation, which yields a considerable advantage for the stability of the method. Given 16 tracks and 2 stages in the cup depth, the plurality of digitally possible quantization stages already amounts to 512. It is also possible to generate the cups in two processing passes in order to increase the plurality of tonal value stages.

The modulators 34 as well as the strip mirror 46 are not shown in Fig. 20. For a better illustration, the cross-section of the ray beam 144 from the terminator of the fiber laser F_{HD1} that is congruent with the ray beam F_{D1} after passing the wavelength-dependent mirror is designed with a hatching. Like all other illustrations, this illustration is not to scale. The two illustrated ray beams 144 yield the processing points B_1 and B_4 on the processing surface 81 that contribute to the built-up of the processing spot 24 and generate corresponding processing tracks on the processing surface 81. The axes of the

terminators 26 and of the ray beams 144 of the individual fiber lasers proceed parallel to one another in Fig. 20. The beam cones of the terminators, i.e. the shape of the ray beam 144, are shown slightly divergent. In the Figure, a beam narrowing within the lens 133 is assumed in the Figure. The divergence angle is inversely proportional to the diameter of the ray bundle in the appertaining beam narrowing. The position of the beam narrowing and its diameter, however, can be influenced by varying the lens 133 in the terminator 26, 94 and/or its distance from the fiber 28 or from the laser fiber 5. The calculation of the beam path ensues in the known way. See the technical explanations on pages K16 and K17 of the general catalog G3, Order No. 650020 of Laser Spindler & Hoyer, Göttingen. The objective is that the processing points B_1 through B_n are the processing surface 81 respectively become beam narrowings in order to obtain the highest power density in the processing points. With the assistance of the two lenses 55 and 56, beam narrowings and track spacings from the object plane 182 wherein the lenses 133 of the terminators 26 lie are imaged demagnified in an intermediate image plane 183 corresponding to the ratio of the focal lengths of the lenses 55 and 56. When, in this case, the distance of the lens 55 from the terminator 26 and from the crossing point 184 is equal to its focal length and when the distance of the lens 56 from the intermediate image plane 183 is equal to its focal length and equal to its spacing from the crossing point 184, what is referred to as a telecentric imaging is obtained, i.e. the axes of the ray bundles belonging to the individual tracks begin to proceed parallel in the intermediate image plane. The divergence, however, has been noticeably increased. The preferably telecentric imaging has the advantage that the diameters of the following lenses 57 and 61 need only be insignificantly larger than the diameter of a ray bundle. The lenses 57 and 61 demagnify the image from the intermediate image plane 183 in a second stage onto the processing surface 81 in the described way. A preferably telecentric imaging, namely that the axes of the individual ray beams proceed parallel between the objective lens 61 and the processing surface 81, has the advantage

here that changes in spacing between the processing surface and the laser gun produce no change in the track spacing, which is very important for a precise processing. The imaging need not necessarily ensue in two stages with two lenses each; there are other arrangements that can also generate parallel beam axes between objective lens and processing surface, as shown in Figures 21 and 22. Deviations in the parallelism of the beam axes between the objective lens 61 and the processing surface 81 can also be tolerated as long as the result of the processing of the material is satisfactory.

Fig. 21 shows a fundamental beam path for the exemplary embodiment of Fig. 4b. The illustration is not to scale. As was already the case in Fig. 20, the two ray bundles 144 of the lasers F_{HD1} and F_{HD4} are only a matter of a subset of the ray bundles of all existing lasers in order to explain the principle. In contrast to Fig. 20, however, the axes of the individual ray bundles of the terminators in Fig. 21 are not parallel but are arranged at an angle relative to one another, which is shown in greater detail in Fig. 24, and which is advantageously achieved by terminators 94 according to Figs. 10, 10a and 10b. As a result of this arrangement, the individual ray bundles 144 would cross similar to the case in Fig. 20 without a lens 55 being required. In the region of the imaginary crossing point, the dispersive lens with a short focal length, i.e. a concave lens 101 is inserted, this bending the incoming rays off as shown and rendering the ray bundles divergent, i.e. widening them. The convex lens 102 is preferably arranged in the intersection of the axial rays and, together with the lens 101, forms an inverted Galileo telescope. As a result thereof, for example, parallel input ray bundles are converted into parallel output ray bundles having an enlarged diameter between the lenses 102 and 103. The desired parallelism of each input ray bundle can, as already described, be undertaken by a suitable selection of focal length and spacing of the lens 133 from the fiber 28 or, respectively, laser fiber 5 in the terminators 26, 94. The objective lens 103 focuses the enlarged ray bundle onto the processing surface 81 at the processing points B_1 through B_4 that contribute to the built-up of the processing spot 24

and generate corresponding processing tracks on the processing surface 81. The imaging scale can be modified in a simple way by modifying the focal length of the lens 103. It is therefore advantageous when the lens 103 is implemented as an interchangeable objective lens. As already described, however, a vario-focusing optics can also be employed. When the position of the lens 103 is selected such that the distance between the lenses 102 and 103 corresponds to the focal length of the lens 103, the axes of the ray bundles between the lens 103 and the processing surface are parallel and yield constant spacings of the tracks of the processing surface, even given a modified between the laser gun and the processing surface.

Fig. 22 indicates the fundamental beam path for the exemplary embodiment of Fig. 4c. Like all other figures, the illustration is not to scale. The beam path is very similar to that of Fig. 21, with the difference that an arced mirror 121 is employed instead of the lens 101 and a concave mirror 115 is employed instead of the lens 102. The beam path is considerably shorter due to the folding that derives. The beam path approximately corresponds to that of an inverted mirror telescope. Mirror telescopes are independent of the wavelength which is advantageous given employment of lasers having different wavelength. The imaging errors can be reduced by employing aspherical surfaces or with an optical correction plate 117 that, however, is not shown in Fig. 22. It is advantageous from the focal length of the objective lens 112 is equal to its spacing from the concave mirror. The axes of the ray bundles are then parallel between the lens 112 and the processing surface 81 and yield constant spacings of the tracks on the processing surface, even given a modified distance between the laser gun and the processing surface. Moreover, an advantageously large spacing of the objective lens from the processing surface derives. As described a vario-focusing optics can also be utilized.

Fig. 23 shows an arrangement having a plurality of lasers, whereby the individual laser outputs in the form of the terminators 26 are arranged on a circular segment and beam at a common cross-over point 185. This

arrangement is particularly suitable for directly modulatable lasers since a very low outlay then derives. In such an arrangement, the imaging on the processing surface 81 can ensue with only a single lens 186. However, an arrangement according to Figs. 4b or 4c can also be employed for imaging. The ray cones of the ray bundles from the terminators are set such that a beam narrowing and, thus, a sharp image derives for all lasers on the processing surface 81. Preferably, the spacings between the cross-over point 185 and the lens 186 as well as between the lens 186 and the processing surface 81 are of the same size and correspond to the focal length of the lens 186. In this case, the axes of the individual ray bundles between the lens 186 and the processing surface 81 are parallel and yield constant spacings between the processing tracks, even given a modified distance between the laser gun and the processing surface. Although not shown, a plurality of levels of lasers can also be arranged above one another in order to increase the power density and the power of the laser radiation source. The planes of the lasers are preferably arranged parallel to one another. As shown in Figs. 29 and 31, but then derives is that the individual ray bundles from the individual planes meet on a spot in the processing points on the processing surface 81 and thus generate an especially high power density.

Fig. 24 shows a modification relating to Fig. 23. Four fiber lasers F_{HD1}, F_{HD2}, F_{HD3}, F_{HD4} have their terminators 94, which are described in greater detail in Figs. 10, 10a and 10b, joined to one another on a circular segment. The terminators 94 are particularly suited for joining to one another as a result of their shape. Since no directly modulatable fiber lasers are employed here, a four-channel acousto-optical modulator 34 is inserted. The piezo-electric sensors 45 can, as shown in Fig. 24, likewise be arranged on a circular segment. As shown in Fig. 24a, however, they can also be arranged parallel as long as the ray bundles are still adequately acquired by the acoustic field of the piezo-electric sensors 45. Instead of the lens 186, a transmission unit as described in Figs. 4b and 4c is advantageously employed.

Fig. 25 indicates a demagnifiying intermediate image with the lense 191 and 192, so that the distance between the individual terminators 26, 94 can be greater than the distance between the individual modulator channels T1 through T4 on the multi-channel acousto-optical modulator 34. The imaging ratio corresponds to the relationship of the focal lengths of the two lenses 191 and 192. The intermediate image is preferably telecentrically fashioned in that the distance of the lens 191 from the lenses 133 of the terminators 26 or, respectively, 94 and from the cross-over point 193 is equal to its focal length, and in that the distance from the crossing point 193 to the lens 192 as well as the distance of the lens 192 from the modulator crystal 34 is equal to its focal length. By adjusting the distance between the two lenses, however, one can also achieve that the rays emerging from the lens 192 no longer proceed parallel but at an angle relative to one another in order to connect the beam path according to Figs. 21 or 22 thereto. An intermediate image according to Fig. 25 can also be employed in combination with an arrangement of the terminators on a circular segment according to Figs. 23 and 24.

The intermediate image (191, 192) is shown in Fig. 25 between the terminators (26, 94) and the modulator (34). However, a wavelength-dependent or polarization-dependent mirror 37 can also be arranged preceeding or following the intermediate image in beam direction. An intermediate image (191, 192) can also be arranged in the beam path following the modulator, before or after the strip mirror 46. Preferably, the intermediate image in the beam path is inserted at the locations referenced "E" in Fig. 4a.

Figs. 26 and 26a show how the distance between the tracks in the processing plane can be reduced. Fig. 26 is a side view and Fig. 26a is the appertaining plan view. Since the ray bundles 144 emerging from the terminators 26, 94 have a smaller diameter than the housing of the terminators, interspaces remain that are not utilized. Moreover, the minimum distances between the tracks and the maximum diameters of the ray bundles are prescribed by the multi-channel acoustic-optical modulators 34. In order to

increase the distances between the tracks, a strip mirror 46 is provided that is transparent and mirrored in alternation in stripe-shaped fashion at intervals. The strip mirror 46 and the modulators are not shown in Fig. 26a. Such a strip mirror 46 is shown in Figures 27 and 27a, whereby Fig. 27a shows a side view of Fig. 27. Highly reflective strips 195 are applied on a suitable substrate 194 that is transparent for laser radiation. The interspaces 196 as well as the backside are preferably provided with a reflection-reducing layer. The ray bundles 144 from the terminators 26, 94 of the fiber lasers F_{D1} through F_{D4} pass unimpeded through the transparent part of the strip mirror 46. The ray bundles 144 from the terminators 26, 94 of the fiber lasers F_{R1} through F_{R4} are arranged such that they are reflected at the strips of the strip mirror such that that they lie in a row with the ray bundles F_{D1} through F_{D4}. The distance between the tracks has thus been cut in half.

Fig. 27b shows a strip mirror 46, whereby the substrate of the mirror was removed in the interspaces 196, and the entire, remaining surface is preferably highly reflectively mirrored, so that strips 195 derive. In this case, the strip mirrors can be preferably manufactured of metal, which is especially advantageous given high powers and the heating connected therewith.

An arrangement having strip mirrors can be combined very well with an arrangement having wavelength-dependent mirrors, as shown, for example, in Figures 4, 4a, 4b, 4c. The further beam path according to Fig. 20 can be connected vi the lens 55. The axes of the individual terminators 26, 94, however, can also be arranged at an angle, as shown in Figs. 23 and 24. In this case, the further beam path can proceed according to Fig. 21 or 22 and the lens 55 is omitted.

Figs. 28 and 28a show how fiber lasers of different wavelength, for example Nd:YAG lasers having 1060 nm and those having a different doping with 1100 nm are combined with one another via a wavelength-dependent mirror 37. The wavelength difference can be less but can also be greater.

The modulators and the wavelength-dependent mirror are not shown in Fig. 28a. Preferably, wavelength-dependent mirrors are optical interference filters that are manufactured by vapor-deposition of suitable dielectric layers onto a substrate that is transparent for the appertaining wavelengths and can have very steep filter edges as high-pass or low-pass filters. Wavelengths up to the filter edge are allowed to pass; wavelengths beyond the filter edge are reflected. Band-pass filters are also possible. Likewise, lasers of the same wavelength but different polarization direction can be combined via polarized beam combiners, preferably polarization prisms. Inventively, a combination of polarized beam combiners and wavelength-dependent mirrors is also possible. In Fig. 28, the ray bundles 144 emerge from the terminators 26, 94 of the fiber lasers F_{HD1} through F_{HD4} with the wavelength λ_1, pass unimpeded through a wavelength-dependent mirror 37, whereas the ray bundles F_{VD1} through F_{VD4} having the wavelength λ_2 are reflected at it and, thus, the two ray bundles are united in one another following the mirror. Each ray bundle can be separately modulated according to the invention via a respective multi-channel, acoustic-optical modulator 34. Since respectively two lasers of different wavelengths process the same track in the same processing point on the processing surface, a digital amplitude modulation in 2 stages is possible in a simple way in order, for example, to control the depth of the cups when producing printing forms for rotogravure when the two participating ray bundles are respectively merely turned on or off. However, a shared modulator for the two united ray bundles can also be employed. In this case, the modulator is arranged between the wavelength-dependent mirror 37 and the lens 55, as shown in Figs. 4, 4a, 4b, 4c. The further beam path of the transmission unit according to Fig. 20 connects via the lens 55. However, the axes of individual terminators 26, 94 can also be arranged at an angle relative to one another, as shown in Figs. 23 and 24. In this case, the further beam path can proceed according to Fig. 21 or 22 and the lens 55 can be omitted.

Fig. 29 shows how fiber lasers with their terminators 26, 94 (Fig. 31) can be arranged in a plurality of planes. Three planes of terminators that are connected to fiber lasers lie above one another. The first track is referenced F_1 for the first plane, with F_2 for the second plane and with F_3 for the third plane. The numerals 11, 12 and 13 reference the first plane of the further tracks. The axes of the ray bundles 144 emerging from the terminators are directed parallel to one another in the individual planes. The axes of the ray bundles of the individual tracks can proceed parallel to one another, as shown in Fig. 20, or at an angle relative to one another according to Fig. 23 or 24.

In Fig. 30, the terminators 26, 94 (Fig. 31) of, for example, seven fiber lasers F_1 through F_7 are arranged in a hexagon such that the axes of their ray bundles 144 are parallel to one another. To this end, terminators according to Fig. 12 can be advantageously employed. As a result thereof, the smallest possible diameter of a common ray bundle composed of seven individual ray bundles derives.

First, Fig. 31 is a sectional view through the three planes of the first track of Fig. 29. A lens 107 collects all incoming parallel rays in its focal point 201 on the processing surface 81. As a result thereof, power and power density are multiplied by the plurality of lasers united in the focal point, i.e. are tripled given three planes. When the axes of the ray bundles emerging from the terminators 26, 94 proceed parallel to one another for tracks and planes, the ray bundles of all tracks would likewise be additionally united in the focal point, and a common processing point would arise on the processing surface that generates a processing track. I.e., the same number of processing tracks are registered next to one another as there are tracks of terminators. The power of the ray beams of the various planes is superimposed in the respective processing point and the power density is tripled in the illustrated example. The individual fiber lasers can thereby be directly modulated; however, external modulators can also be employed. Figs. 32 and 33 describe how a multiple-channel acousto-optical modulator corresponding to the plurality of tracks can

be preferably employed for the simultaneous modulation of all ray bundles of the various planes.

Fig. 31 is also a sectional view through the bundle arrangement according to Fig. 30. It is known that parallel ray bundles that are incident into a lens have a common focus. Page 13, Fig. 2.21 in the book "Optik und Atomphysik" by R. W. Pohl, 13th edition, 1976, Springer Verlag shows such an arrangement. Further, DE-A-196 03 111 discloses an arrangement wherein, as can be seen from Fig. 1 therein, the radiation from a plurality of laser diodes is respectively coupled into a single-mode fiber, the radiation at the output of each fiber is collimated to a respective, parallel ray bundle, and all parallel ray bundles are directed onto a common spot with a shared lens in order to achieve an increased power density. Compared to the arrangement shown in Fig. 31 with fiber lasers, however, this arrangement has serious disadvantages. When, namely, radiation is to be efficiently coupled into single-mode fibers, single-mode laser diodes are required for this purpose so that the aperture of the single-mode fibers is not overfilled and the total radiation can be transmitted into the core of the single-mode fiber. Single-mode laser diodes, however, can only be manufactured with extremely limited power because the loadability of the minute laser mirrors represents a technological barrier. Single-mode laser diodes are therefore only available up to an output power of approximately 200 mW and are far more expensive per watt then multi-mode diodes that are offered with radiation powers of up to several kilowatts. Given single-mode fibers for 800 nm wavelength, the product of core diameter and numerical aperture amounts to approximately 5 μm x 0.11 = 0.55 μm, whereas this lies at 300 μm x 0.4 = 120 μm given a fiber laser having a typical diameter of the pump fiber of 300 μm and a numerical aperture of 0.4, which amounts to a factor of 220. When the area ratio of the two fibers is considered, then a factor of $(300/5)^2 = 3600$ derives. Even when a reduction of the laser radiation by the factor of the absorption efficiency of approximately 0.6 is assumed given the fiber laser, this being the efficiency with which the pump radiation is converted

into laser radiation, the power of the laser radiation that can be achieved at the output of a fiber laser is several orders of magnitude higher then the power at the output of a single-mode fiber. Even if single-mode diodes or other laser radiation sources having very high power were available, it would nonetheless not be possible to couple this satisfactorily into single-mode fibers, since the fibers would burn given the slightest misadjustment at the fiber entry. This problem does not exist given fiber lasers since a relatively large fiber diameter is available for the pumping and the energy is transmitted into the single-mode core of the laser fibers only within the laser fiber, which is possible unproblemmatically and with good efficiency.

The lens 197 in Fig. 31 unites the entire power of all seven ray bundles F_1 through F_7 of the corresponding fiber lasers in its focal point 201 which represents the processing spot 24 on the processing surface 81. The power and the power density in the focal point thus become higher by the factor of 7 than is the case given an individual ray bundle. When, for example, 100 W are required in order to generate a required power density on the processing surface, then seven lasers having a radiant power of approximately 15 watts each suffice in this case. However, more than seven lasers can be provided. The lasers can preferably be directly modulated. However, it is also possible to modulate all seven ray bundles separately or overall with an external modulator or to supply a plurality of such bundle arrangements to a multi-channel modulator in such a way that the modulator channels are preferably arranged in the focal point of a uniting lens 197 that is allocated to each bundle. It is also possible to couple the multiplied power of each and every bundle into fibers before or after the modulation. Further, such bundle arrangements can be advantageously utilized in laser guns according to Figs. 4, 4a, 4b, 4c.

It is advantageous to separately modulate the individual lasers. This is especially suitable when a high number of lasers is employed, since, for example, a quantized modulation that is similar to an analog modulation, a quasi-analog modulation of the united laser radiation is then enabled by digital

modulation of the individual lasers. However, it is also possible to modulate the ray bundles 144 of all lasers in common, for example with an acousto-optical modulator. In this case, the ultrasound field of the modulator cell must exhibit such a size that the overall ray bundle shown in Fig. 30 can be modulated. However, the switching time of the acousto-optical modulator becomes so great as a result thereof that the shape of the cups to be engraved is disturbed as a consequence of the rotational movement of the drum containing the processing surface. However, it is possible to entrain the laser beam with a deflection motion in the direction of the rotary motion of the printing cylinder to be engraved during the engraving and to thereby achieve a processing spot 24 that is stationary on the processing surface. Inventively, the deflection motion can ensue with the same acousto-optical modulator with which the amplitude modulation ensues. However, another acousto-optical cell can also be utilized, the deflection ensuing therewith.

Fig. 32, in a farther-reaching example, shows how the power density on the processing surface can be considerably increased by providing terminators 26, 94 with the appertaining fiber lasers in a plurality of planes, but a modulation of all ray bundles 144 belonging to a track can be simultaneously implemented with a single-multi-channel, acousto-optical modulator 34 corresponding to the plurality of tracks. In this example, the terminators are arranged in three planes of n tracks each that lie above one another. The power of all ray bundles 144 of all planes should be largely focused in a processing point in the processing surface for each track in order to achieve a high power density. The terminators 26, 94 are arranged parallel to one another in tracks and planes, in that the terminators 26 are joined to one another in close proximity. As shown, terminators having a round cross-section can be employed for this purpose; preferably, however, terminators having a quadratic cross-section according to Figs. 9 and 9a are utilized. Given the parallel arrangement of the tracks, the illustrated imaging system having the cylindrical lenses 202 and 203, also refer to as cylinder optics, can, for example, be added

analogous to an arrangement like that of Fig. 4. When the individual tracks are to proceed at an angle according to Figs. 23 or 24, terminators 94 according to Figs. 10, 10a and 10b are preferably employed. In this arrangement, too, the ray bundles of the individual planes remain parallel; the fits of the terminators 94 should proceed parallel in the side view of Fig. 10a for this purpose. When the axes of the ray bundles for the tracks proceed at an angle relative to one another, the cylinder optics having the lenses 203 and 203 [sic] can be added, for example analogous to the arrangements according to Figs. 4b or 4c. The ray bundles 144 emerging from the terminators are directed onto the convex cylinder lens 202 that would ignite the rays in its focus to form a line having the length of the beam diameter. A concave cylinder lens 203 having a shorter focal length then the cylinder lens 202 is attached such in the region of the focus of the cylinder lens 202, 203 having a long focal length that its focus coincides with the focus of the cylinder lens 202. As a result thereof, the rays that leave the lens 203 become parallel again. The spacings between the individual planes, however, have been reduced by the ratio of the focal lengths of the two cylinder lenses compared to the spacings that the ray bundles had when they left the terminators 26, 94. The spacings of the ray bundles have remained unmodified in the direction of the tracks since the cylinder lenses exhibit no refractive effect in this direction. As a result thereof, elliptical beam cross-sections derive in the modulator. The purpose of this arrangement is to make the overall height of the three ellipses lying above one another so small that it approximately corresponds to the major axis of the ellipses in order to create conditions in the channels of the acousto-optical modulator similar to those achieved given a round beam cross-section so that, for example, similarly short switching times can be achieved.

Fig. 33 shows that, however, the spacing of the two cylinder lenses can also be modified somewhat so that all three elliptical ray bundles overlap in the modulator, this is in fact yielding a shorter switching time in the acousto-

optical modulator but also yielding an increased power density in the modulator crystal. The cylinder lens 203 can also be omitted for this purpose.

The cylinder optics (202, 203) is shown in Fig. 25 between the terminators (26, 94) and the modulator (34). However, a wavelength-dependent or polarization-dependent mirror 37 can also be arranged preceding or following the cylinder optics in beam direction. A cylinder optics (202, 203) can also be introduced in the beam path following the modulator, preceding or following the strip mirror 46. Preferably, the intermediate image is inserted in the beam path at the locations references "E" in Fig. 4a.

For removing the material eroded from the processing surface, Fig. 34 shows a mouthpiece 82 whose main job is to use a directed flow to see to it that optimally no clouds of gases and/or eroded material form in the optical beam path between objective lens and processing service 81, these clouds absorbing a part of the laser energy and depositing on the processing surface and thus negatively influencing the work result.

As a result of its specific shaping, the mouthpiece 82 prevents the described disadvantages. Preferably, it is secured to the laser gun with connections 204 that are simple to release, so that it can be removed and claimed in a simple way and also enables a simple cleaning as well as a simple replacement of the objective lens (not shown) 61, 103, 112. A cylindrical bore 206 for adaptation to the objective lens and a preferably conical bore 207 as passage for the ray bundle as well as another preferably cylindrical bore that represents the processing space 211 are located in a preferably cylindrical base member 205. The distance of the base member 205 from the processing surface 81 should not be excessively great. The processing points (not shown) for producing the individual processing tracks on the material to be processed lie in the processing spot 24. A broad, all around extraction channel 212 is preferably located in the base member, this channel 212 being connected to the processing space 211 via a plurality of extraction channels 213 that should have a large cross-section. Preferably, 3 through 6 extraction channels 213 are present. A

further, preferably all around admission channel 214 is located in the base member, this channel 214 being connected via nozzle bores 215 to the processing space 211 and to the conical bore 207 via smaller bypass bores 216. 3 through 6 nozzle bores 215 and 3 through 20 bypass bores 216 are preferably distributed over the circumference of the admission channel 214. All bores can be offset relative to one another and relative to the extraction channels 213 on the circumference. Further bypass bores can also be attached and directed onto the objective lens. This, however, is not shown. The base member is surrounded by a ring 217 applied gas-tight that contains a plurality of extraction connectors 221 in the region of the channel 212 to which extraction hoses are connected, these being conducted via an extraction filter to a vacuum pump. Extraction hoses, extraction filter and vacuum pump are not shown in Fig. 34. In the region of the channel 214, the ring contains at least one admission connector 222 via which compressed air filtered with an admission hose is supplied. The quantity of admitted air can be set such with a valve that it is just adequate in order to adequately rinse the processing space and such that it generates a slight air stream along the conical bore via the bypass bores that largely prevents a penetration of particles into the conical bore. Admission hose, valve and filter are not shown in Fig.3 4. The nozzle bores 215 are directed such onto the processing spot 24 that the clouds of gas, solid and molten material arising in the processing are quickly blown out of the beam path so that these absorb as little laser energy as possible and cannot negatively influence the processing result. Oxidation-promoting or oxidation-inhibiting gases or other gases can also be blown in with the admission air, these having a positive influence on the processing process. A slight quantity of air from the environment co-flows through the processing space to the extraction channels through the gap between the processing surface and the base member 205; this, however, is not shown. The filter in the extraction line is attached easily accessible in the proximity of the mouthpiece and sees to keeping the vacuum pump clean. It is also possible to introduce the filter directly in the extraction

channel 212. As described under Fig. 39a, it is useful when a protective atmosphere is additionally conducted over the objective lens. If the mouthpiece 82 becomes too hot due to the laser radiation reflected from the processing surface and the air that flows through does not suffice for cooling, then the mouthpiece can be provided with additional bores through which a coolant is pumped; this, however, is not shown in the Figs. A glass plate 218 that is highly anti-bloomed on both sides and is simple to change can also be located within the cylindrical bore 205, this glass plate 218 keeping dirt particles away from the objective lens the shape of the mouthpiece can also deviate from the form that is described and shown. For example, the bores need not be cylindrically or conically implemented, as described; they can be varied in shape. Likewise, for example, the nozzle bores and extraction channels can assume arbitrary shapes and can also be asymmetrically arranged. For example, the nozzle bores in Fig. 34 can be arranged more in the upper part of the Fig., whereas the extraction channels lie more in the lower part of the Figure. For example, the nozzle bores and/or the bypass bores can also be foregone. The shape of the mouthpiece can also be modified, particularly when the shape of the processing surface and the type of relative motion between processing surface and laser radiation source demand this. It is conceivable to utilize a modified form of the described mouthpiece when the material to be processed is located, for example, on a planar surface instead of on a drum surface, and the laser radiation is conducted past this line-by-line. In this case referred to as flatbed arrangement, which is shown in greater detail in Figures 43, 43a and 43b, the mouthpiece is implemented elongated corresponding to the line length and is provided with an elongated processing space corresponding to its length. The mouthpiece is equipped with nozzle bores and extraction channels from one or from both sides. In this case, the glass plate would be given a rectangular shape and would extend over the entire length of the arrangement. In this case, Figure 34 could be analogously considered as a cross-section of the elongated mouthpiece. Even when the material to be processed is located in a

hollow cylinder, which is not shown in detail in Figs 44a and 44b, a similar mouthpiece can be produced in that the mouthpiece described for the flatbed arrangement is adapted in longitudinal direction such to the shape of the hollow cylinder that a slight gap between the processing surface and the mouthpiece derives over the entire length. The glass plate would be given a rectangular shape in this case and would be curved over the entire length of the arrangement.

In a known scraper device that, however, is not shown in the figures can be located in the proximity of the mouthpiece but need not necessarily be connected to it or to the laser gun. For example, the job of the scraper device is to scrape off the ejects arising at the edges of the cups during the processing process at rotogravure forms. Further, a brush device (not shown) can preferably be located in the proximity of the laser gun, this brushing out the cups that have been cut and ridding them of adhering dirt. Further, a measuring device (not shown) can be preferably inventively located at the laser gun, this measuring the position and/or the volume of the cups immediately after they are produced. In contrast to cups that have been manufactured by electro-mechanical engraving or with a single laser beam, the volume can be inventively more precisely identified for cups that are produced with inventive laser radiation source and have steep edges and constant depth, in that the area of the cup is determined with a specific, fast camera and the volume is derived therefrom. It is thereby advantageous to measure a series of cups in order to reduce measuring errors. It lies within the framework of the invention that specific control fields are engraved in a region of the rotogravure cylinder, this being provided for monitoring measurements and/or for monitoring prints. A rated/actual comparison can be produced with this measured quantity for the generated cups and with the cup size prescribed for this location. The result can then be employed in order to correct the position and/or the volume of the subsequently produced cups.

Fig. 35 shows the conditions on the processing surface. The processing points are identified with the indices that indicate the ray bundles of the fiber lasers according to Figs. 4, 4a, 4b and 4c that produce them. For example, the ray bundles of the fiber lasers F_{VR1} and F_{HR1} generate the processing point $B_{FVR1+FHR1}$ in common the diameter of the processing points is referenced B, their spacing is referenced A. In the multi-channel, acousto-optical modulator described under Figs. 19 and 19a, the allowable diameter of the ray bundle 144 is smaller than the spacing of the channels of the modulator. The diameter of the ray bundle 144 in the terminators 26, 94 can also be made just as large as the outside diameter of the terminators without great outlay. It follows therefrom that A is thus greater than B. This leads to undesired interspaces at the processing tracks 224 that derive as a result of the relative motion between the material to be processed and the laser gun. The processing tracks have a track width D that correspond [sic] between the diameter of the processing points B and R [sic] referenced 1 through 8 in Fig. 35. In order to reduce these interspaces, two beam packets were already nested inside one another with the strip mirror, as described under Figs. 4, 4a, 26 and 26a, in order to cut the interspaces in half. In order to reduce the remaining interspaces even more or entirely avoid them or cause the processing tracks 224 to overlap, the laser gun can be turned such compared to the relative motion direction between the material to be processed and the laser gun that the tracks come closer to one another, this being shown in Fig. 35. In order, for example, to achieve a spacing C of the processing tracks 224 that is equal to the diameter B of the processing points, the laser gun must be turned by the angle β according to the relationship $\cos \beta = B/A$. Distortions in the image information arise on the processing surface due to the rotation of the laser gun, since the starts in the individual processing tracks are now shifted relative to one another. These distortions, however, are already compensated in the editing of the processing data. It is also possible to undertake this compensation by an adjustable, different delay of the signals in the individual data channels immediately before

the modulation or to simply accept the distortions. Further possibilities for setting and reducing the spacings of the processing tracks are presented in Figs.36, 36a, 36b, 36c and 37.

Fig. 36 shows the principle of how processing points B_1...B_4 derive on the processing surface 81 when the individual channels are charged with different frequencies f_1 through f_4 in a multi-channel acousto-optical modulator 34 having four separate channels. For example, the modulator channel T_1 (Fig. 36a) is thereby supplied with a frequency f_1, whereby f_1 is provided with a higher frequency compared to f_4 in the modulator channel T_4 (Fig. 36a), so that a greater spacing of I_0 derives for the processing track 1 than for the processing track 4. The channels T_2 and T_3 are provided with corresponding frequencies f_2 and f_3 in order to achieve the illustrated arrangement of the processing tracks 224. However, the frequencies can also be arranged such that the frequency f_1 is lower then the frequency f_4. It is also possible to arbitrarily allocate the frequencies f_1 through f_4 to the individual modulator channels T_1 through T_4. In this case, a lens 165 as shown in Fig. 17 and Fig. 36a is not absolutely necessary; rather, the laser radiation emerging from the terminators can be focused such that a sharp image derives in the processing points on the processing surface.

How the ray bundles focused by the lens 165 impinge the generated line M of the drum is shown in Fig. 36a with reference to an example (not to scale) with rotating drum on which the processing surface 81 lies. The position of the puncture points P of the ray axes with the plane of the lens 165 thereby corresponds to the principle of Fig. 36. To that end, the modulator 34 with the channels T_1 through T_4 is correspondingly arranged relative to the ray bundles 144 of the fiber lasers F_1 through F_4. What is achieved by a suitable selection of the frequencies f_1 through f_4 is that the partial rays that generate the processing points B_1 through B_4 lie at desired distances from one another in the direction of the generated line M. This has the advantage that the position of each processing point and, thus, of each processing track 224 can be individually set

by adjusting the appertaining frequency. A particular advantage of the arrangement derives when, as indicated in Fig. 17, the multi-channel acousto-optical modulator is arranged approximately in the one and the processing surface is arranged approximately in the other focal point of the lens 165 and the axes of the ray bundles of the fiber lasers F_1 through F_4 are arranged approximately in parallel planes. The processing points B_1 through B_4 then lie in a row on the generated line M (36a), and the axes of the partial rays that form the processing points are parallel and reside perpendicularly on the processing surface (Fig. 17). Another advantage of the arrangement is comprised therein that the Bragg angle for optimizing the efficiency can be individually set for each modulator channel, but this is not shown in the Figures. In this example, the deflected rays are used for processing material, whereas the non-deflected rays I_0 are blanked out by an intercept arrangement similar to that shown in Figure 18. In contrast to the arrangement in Figure 18, it is shown here that the mirror 166 acting as intercept arrangement can also be arranged between the lens 165 and the processing surface. As described under Fig. 4, however, the intercept arrangement can also be foregone when a symmetrical or asymmetrical defocusing reduces the radiation that is contained in I_0 and is unwanted for processing in terms of its power density to such an extent that no processing effect is produced when it is directed onto the processing surface.

Fig. 36b shows an expanded embodiment of Fig. 36a in a side view. The lenses 202 and 203 are inserted between the multi-channel modulator with the channels T_1 through T_n, said lenses 202 and 203 being preferably cylinder lenses and forming a cylinder optics, as described under Fig. 32 and Fig. 33. This cylinder optics [...] demagnified distance between the channels T_1 and T_n at the location of the lens 166 and, given a predetermined focal length of the lens 165, thus, the angle at which the rays of the individual channels T_1 through T_n impinge the processing surface, which is particularly significant given a great number of channels and significantly favors the costs for the lens 165, which can also be a system composed of a plurality of lenses, as well as its makeability.

Fig. 36c shows a plan view relating to Fig. 36b, from which it can be seen that the cylinder optics exhibits essentially no effect in this view. The ray bundles F_1 through F_n coupled into the acousto-optical modulator 161 are in fact shown under the same Bragg angle; however, they can also, however, be coupled in individually different under the respectively optimum Bragg angle.

Fig. 37 emphasizes another advantage of the arrangements according to Figs. 36, 36a, 36b and 36c, namely that respectively two processing points B_{11}, B_{12} through B_{41}, B_{42} can now be generated instead of the processing points B_1 through B_4 by simultaneous application of two different frequencies to the respective modulator channels. Instead of four processing tracks, eight separately modulatable processing tracks 224 have now arisen without increasing the number of lasers and/or the number of modulator channels. It lies within the scope of the invention to also employ more than two frequencies per modulator. Twelve different frequencies with a single modulator channel have already been realized for a similar purpose. Another advantage in the generation of processing points with acousto-optical deflection is the possible shift of the processing points at high deflection speed. By modifying the applied frequencies, individual or all processing tracks 224 can be very quickly displaced relative to their previous position and there is thus a further possibility of beneficially influencing the position and shape of the cups. With this measure, in particular, the position of the processing tracks can be correspondingly readjusted to a rated quantity with high precision. Precisions of a fraction of a track width are thereby possible. Inventively, the actual position of the individual processing tracks can be precisely determined with a known, interferometrically functioning measuring system in that, for example, the actual position of the laser radiation source is registered during the processing event and a correction signal for the required displacement and readjustment of the processing tracks is generated by comparison to the rated position of the processing tracks. This can be of interest particularly when a seamless join is to be made to a processing pattern that already exists or when a

pattern that already exists is to be post-processed. Another enormous advantage of the arrangement is comprised therein that the Bragg angle can be individually set for optimizing the efficiency for each modulator channel, which, however, is not shown in the Figures. Up to now, acousto-optical arrangements wherein a plurality of sub-beams are generated from a laser beam by applying a plurality of frequencies and all of these have a shared Bragg angle for all sub-beams has not yet made a breakthrough in processing of materials because the efficiency is too low. When, however, a combination of a plurality of laser beams having respectively individually set Bragg angle and a plurality of acousto-optically generated sub-beams per laser beam is selected as proposed, then a clearly higher efficiency can be achieved, so that a great plurality of simultaneously acting processing tracks can be realized for processing material.

As described under Figs. 18 and 18a, however, single-channel or multi-channel electro-optical modulators can also be utilized in conjunction with a birefringent material in order to split each laser beam into two beams that can be separately modulated via further electro-optical or acousto-optical modulators.

It has been emphasized that the processing of the material in Figs. 36, 36a, 36b, 36c and 37 should ensue with the deflected laser beams and that the radiation contained the non-deflected ray laser beam is to be neutralized, so that no processing effect is produced. This, however, is not absolutely necessary, and instances are conceivable wherein one works conversely. A further advantage of the arrangement shall therefore be cited and explained with reference to Fig. 36a: wherein one wishes to employ the radiation contained in the laser beams I_0 for processing material, the mirror 166 is removed. The entire radiant power from all four lasers F_1 through F_4 thus derives [sic] on the generated line in a spot. More than four times the power density thus derives in the spot compared to the previous processing points B_1 through B_4, and it can be assumed that no processing effect arises in B_1 through B_4 given specific materials and process parameters. Ie., the processing surface simultaneously

serves as sump for the radiation that is not intended to produce any processing effect. This is advantageous since a thermal equilibrium occurs on the processing surface since the entire laser energy is supplied to the processing surface in every case. It lies within the scope of the invention that fewer or more than four lasers with appertaining modulator channels are utilized and that the difference in the power density between the radiation that is intended to produce a processing effect and the radiation that should not produce any processing effect is increased per modulation channel by employing more than one frequency per modulator channel. It also lies within the framework of the invention that the described principle can be advantageously applied when the laser beam incident into the acousto-optical modulator has high divergence, as is the case, for example, when the acousto-optical modulator in an arrangement according to Fig. 31 is to be arranged in the proximity of the focal point 201 or in arrangements wherein the laser has an especially great divergence. In Fig. 31, for example, the axis of the ray bundle emerging from the laser F_2 is intended to represent the position of the optimum Bragg angle for a specific frequency. In this case, the Bragg condition is met far more poorly for the one frequency for the rays at the edge of the ray bundle, for example of the lasers F_1 and F_3, than for the central rays of, for example, the laser F_2, and only a slight part of the radiation is deflected, which means low contrast for the modulator. When, however, a plurality of frequencies are simultaneously applied to the acousto-optical modulator and when these frequencies are selected such that they are optimum both for the outer as well as for the middle incident ray bundle with respect to the Bragg angle, the highest possible contrast derives and the highest possible difference in the power density arises on the processing surface between the radiation that is intended to produce a processing effect and the radiation that should not produce any processing effect.

Fig. 38 shows how dexterous arrangement of the components in the optical beam path can see to it that the laser ray bundles never perpendicularly impinge the optical surfaces. This prevents a part of the radiation from being

reflected from these surfaces back into the lasers. When, namely, energy proceeds back into a laser, an excitation occurs in the laser and the laser begins to oscillate in terms of the amplitude of the radiation that is output. The output power is thus no longer constant and patterns are formed in the process surface that can make the result unuseable. Fig. 38 shows the axial rays of two planes; the lasers, however, can also be arranged in one or more planes as long as the symmetry axis for the two axes that are shown is not used. For reasons of function, the acousto-optical modulator is already turned by the angle α_B. In order, however, to be certain that energy is not reflected back into the laser as a consequence of the changing ultrasound field, the modulator can be additionally turned by the angle γ, as shown in Fig. 38. Another possibility for avoiding oscillations of the laser is the insertion of one or more optical components at suitable locations in the beam path that only allow laser radiation to transmit in one direction. For example, what are referred to as Faraday isolators can be employed for this purpose, as described under Fig. 20 in said catalog of Spindler and Hoyer on page F2. Such isolators are not shown in the Figures.

Fig. 39 shows a lens 101 whose mount contains bores 87 that preferably surround the lens in a plurality of turns and have a coolant flowing through them. Given high-power arrangements, the absorption of the optical medium of the lenses can be left out of consideration. Moreover, a slight part of the radiation is dispersed by every optical surface even given the best anti-blooming and is absorbed by the mount parts. A cooling of the lens mounts is therefore meaningful. It has already been mentioned that materials having high thermal conductivity and low absorption such as, for example, sapphire are advantageous for the most stressed lenses. Sapphire also has the advantage that the lens surface does not scratch when cleaning due to the greater hardness of the material. One should also see to a good contacting of the optical medium with the mount. This is advantageously achieved by a metallization of the edge

zone of the optical element and by a soldering 223 to the mount. Metallic solders [...] a better heat conduction than glass solders.

It is also possible to cool the critical component parts of the laser gun 23 and of the pump source 2 with the assistance of what are referred to as micro-channel coolers, as described in the article "Lasers in Material Processing" in the publication SPIE Proceedings, Vol. 3097, 1997.

Fig. 39a shows a section through an inventive mount 118 for the objective lens 61, 103, 112 that, for example, is secured with a thread to the tube body 95, 96 or to the mount 116 and is sealed with a seal 125. The objective lens can be glued into the mount or, preferably can be metallized at its edge and soldered into the mount. The mount can be provided with one or more bores 120 through which a protective atmosphere that comes from the interior of the optical unit 8 flows and, for example using a channel 119, is conducted via the side of the objective lens 61, 103, 112 pointing toward the processing surface in order to prevent a contamination of the objective lens by particles of material or by gases that are released during the processing.

Fig. 40 describes a further possibility for preparing fiber lasers or optical fibers, preferably single-mode fibers, for an arrangement in tracks and planes with small spacing. The fiber 28 or, respectively, laser fiber 5 is ground on all sides at the last end to such an extent that a side length arises that is reduced to such an extent that the exit points of the laser radiation 13 lie at a required, slight spacing. In this case, the terminators 26, 94 can be omitted, and an especially simple structure derives. The surfaces that reside opposite can thereby proceed in pairs parallel to one another or at an angle, or one pair proceeds parallel and the other pair proceeds at an angle relative to one another, as was already described for the terminators under Figs. 9 and 10.

Fig. 40a shows a plan view onto or, respectively, a cross-section through the ground laser fiber. The cross-section can preferably be rectangular or quadratic; however, it can also have all other shapes.

Fig. 40b shows a side view of the fiber bundle wherein the fibers were processed similar to Fig. 40, so that the axes of the individual ray bundles 13 proceed nearly parallel.

Fig. 40c represents a side view of the fiber bundle wherein the fibers were processed wedge-shaped, so that the axes of the individual ray bundles 13 intersect outside the fiber bundle.

Fig. 40d again shows a side view of the fiber bundle wherein the axes of the individual fibers in fact proceed parallel but the exit faces of the individual fibers are arranged at different angles ε relative to the fiber axis, so that the axes of the individual ray bundles 13 intersect within the fiber bundle.

Fig. 41shows how a receptacle with four tracks can be produced from ground fibers or laser fibers according to Fig. 40 and Fig. 40a, Fig. 40b, Fig. 40c, 40d. A receptacle in a plurality of planes is shown in broken lines in Fig. 41 in the form of two further planes. The receptacle is also not limited to four tracks and three planes; the laser outputs can be arranged in an arbitrary plurality of tracks and planes according to this principle. On the basis of a corresponding shaping when grinding the fibers, it is possible to determine the spacings between the exit points of the laser radiation 13. For example, the spacing can be implemented such that the laser radiation of the individual plans overlaps such on the processing surface 81 that only tracks derive or such that the individual tracks overlap such that only planes derive. The spacings between the exit points of the laser radiation 13, however, can also be selected such that the laser rays of all tracks and all planes overlap in a point on the processing surface. To this end, the fiber lasers or optical fibers can also be arranged in a bundle.

The principle of the described arrangement of laser outputs in a plurality of planes or in a plurality of tracks or in a plurality of tracks and in a plurality of planes or overlapping in a point also inventively applies to the laser rays incident on the processing surface 81. A plurality of tracks or a plurality of levels or a plurality of tracks and a plurality of levels of laser beams can

likewise be arranged on the processing surface according to this ordering principle or the laser beams can be arranged overlapping in a point.

The arrangement according to Figs. 40, 40a, 40b, 40c, 40d and 41 is particularly suited for directly modulatable lasers. However, external modulators can also be employed. The emerging ray bundles can be imaged into the processing surface with the known arrangements; however, a receptacle can also be implemented, whereby the ray bundles are directly directed onto the processing surface, i.e. without transmission unit, in that, for example, the outputs of a laser radiation source according to Fig. 41 are brought extremely close to the processing surface or lie on the surface of the material in sliding fashion, this yielding an especially simple arrangement. Such a method can be employed, for example, when convergence in the surface of the material are to be excited by energy irradiation or when a material transfer is to be undertaken. In the example of a material transfer, a thin film is placed onto the material to be provided with images that, for example, can be a printing cylinder, an offset plate, an intermediate carrier or the material to be printed itself, a layer being applied to the underside of said thin film that faces to the material to be provided with images and that is stripped by energy irradiation and can be transferred onto the material to be provided with images.

Fig. 42 shows another embodiment of the laser radiation source that can be employed for multi-channel cutting and incising of, for example, semiconductor materials and as [...] in German Patent Application P 198 40 936.2 of the assignee "Anordnung zum mehrkanaligen Schneiden und Ritzen von Materialien mittels Laserstrahlen" running parallel with and filed simultaneously with the present patent application. The terminators 26, 94 of the fibers or, respectively, fiber lasers F_a through F_n have ray bundles 144 that are focused with the lens 133 at a predetermined distance from the terminator. The diameter of the processing points B_a through B_n amounts, for example, to 20 μm; however, it can also lie thereabove or therebelow. Further, the terminators are arranged such on a profiled rail 256 described in greater detail

in Figs. 42 and 42b that their mutual spacing "A" can be set to arbitrary values until the terminators meet one another. The profile rail is preferably secured to an arm of a robot (Fig. 42c) and can, for example, be moved in the directions x, y, z relative to ta table 225 with actuating drives that are shown in Figure 42c. Moreover, the profiled rail can be turned relative to the table by an angle φ having the axis z' (Fig. 42c), which can also be utilized for determining the mutual spacing of the processing tracks. In the exemplary embodiments according to Figs. 4, 4b, 4c, 43, 44, the laser gun is turned around the axis of the tube 51, 95, 113 in order to vary the spacings between the processing tracks. Further, the table can be moved in the directions x, y, z and can be turned by an angle φ with the axis z. The material to be processed, for example one or more, what are referred to as "wafers" separated from a drawn semiconductor ingot, can be secured on the table 225 with clamp or suction devices (not shown). For example, fine, parallel tracks as needed, for example, for contacting photo-voltaic cells, can be incised into the semiconductor material with the laser energy in the individual processing points B_1 through B_n. However, fine bores can also be introduced into the semiconductor material or it can be cut with the laser in order, for example, to thus separate electrical circuits from one another. An inventive arrangement for removing the material 249 (Fig. 42c) eroded from the processing surface is attached close to the processing surface 81 for each processing track 224 separately or for a plurality of processing tracks 224 in common, the functioning of said arrangement being described in detail in Fig. 34. When the profiled rail with the terminators is turned relative to the table in order to modify the spacing between the processing tracks, it is inventively expedient to compensate the distortion of the pattern to be registered that arises due to the relative rotation by a pre-distortion of the pattern to be applied and/or to compensate it with a time control of the data stream. On the basis of the turning, it is also possible to intentionally demonstrate [sic] different line spacings given relative motions in x-direction and in y-direction. Further contacting of the photo-voltaic cells, for

example, two different line patterns are required: a first pattern wherein the incised lines following the metallization produce the contact to the semiconductor material should have spacings of a few millimeters between the individual lines and should, for example, proceed in x-direction. Further, what are referred to as bus bars are required that proceed at a right angle relative to the contact lines and connect these to one another. These lines forming the bus bars should, for example, proceed in y-direction and lie close to one another so that they act like a closed band following the metallization. Inventively, such a pattern can be very simply manufactured in that the profiled rail with the terminators is turned to such an extent until the desired pattern derives. Due to the parallel arrangement of a plurality of fiber laser outputs, the time required for the processing can be considerably shortened; for example, ten laser outputs can be employed in parallel for the incising of the photo-voltaic elements 10, this increasing the output by the factor 10.

The described arrangement for cutting and incising is not only suitable for processing semiconductor materials but can be employed for all materials wherein the precise production of patterns is important such as, for example, in manufacturing printing forms.

Fig. 42a and the appertaining sectional view of Fig. 42b show how the terminators 26 of the individual fiber lasers F_a through F_n are secured. The profiled rail 256 is secured to a carrier 260 with connections 261, said carrier potentially being, for example, the arm of a robot. The terminators 26 are accepted in mounts 257 and fixed with screw 259. The mounts 257 are provided with a profile mating with the profiled rail 256, are placed in a row onto the profiled rail 256, are set at predetermined intervals "A" from one another and are fixed with the screws 259. Due to an inventively small structure of the terminators 26 and of the mounts 257, a very slight spacing"A" is possible. The profiled rail with the terminators can be conducted across the processing surface with the robot for the purpose of processing the material, as shown in Fig. 42 and described in detail. The required movements for

producing the processing tracks can be executed by the table 225 described in Fig. 42 that can also be carried out by the arm of the robot. Preferably, the arm of the robot can also undertake a rotatory motion around the rotational axis z' of the arrangement that is approximately parallel to the axis of the terminators. With this rotation and a relative displacement between the arm of the robot and the table 225, it is possible to modify the spacing of the processing tracks generated on the processing surface 81 and to preferably set them smaller than corresponds to the dimension "A" that has been set.

Fig. 42c indicates an example of the robot that can be constructed, for example, of components of Montech-Deutschland GmbH, Postfach 1949, 79509 Lörrach. A horizontal-linear unit 263 is secured on a stand system "Quickset" 262, said unit 263 in turn accepting a vertical-linear unit 264 having a rotatory drive 265. The actual robot arm 260 is seated at the rotatory drive, the profiled rail 256 being secured to said arm 260 with the connection 261. Another horizontal-linear unit is possible but not shown.

The various motion directions of the table 225 can be realized with the same element, whereby the motion directions can also be partly allocated to the table and partly to the profiled rail. The housing for the acceptance of individual components, the cooling system, the control for the lasers, the pump sources for the fiber lasers, whereof only the terminators 26, 94 are shown, the arrangement for removing the material eroded from the processing surface and the machine control for the drives are not shown in the Figures.

Fig. 43 shows a further flatbed arrangement with the inventive laser radiation source. The material to be processed with the processing surface 81 is located on a table 247 that is seated on guides 251 and can be moved in the feed direction u precisely with a spindle 252. The spindle 252 is placed into rotation by a motor 254 via a gearing 253 that is driven proceeding from a control electronics 255. The laser radiation emerging from the laser gun 23 generates the processing points B_1 through B_n in an intermediate image plane 228 (not shown here) that, for example, is shown in Fig. 44. The laser radiation is

conducted via deflection mirror 241 and an optics 242 belonging to an optical unit onto a rotating mirror 243 that, for example, can have one mirror face that, however, can also be fashioned as a rotating mirror having a plurality of mirror faces and that is placed into a rotatory motion by a motor 244 driven proceeding from the control electronics 255. The rotating mirror 243 steers the laser radiation over the processing surface line-by-line in arrow direction v. An optics 245 belonging to the optical device is located between the rotating mirror and the processing surface, the job of said optics 245 being to generate a sharp processing spot on the processing surface over the entire line length, this processing spot being potentially composed of a plurality of processing points B_1' through B_n' that are shown in Fig. 43. As a result of the rotation of the rotating mirror, the processing points generate processing tracks 224 on the processing surface 81 as shown, for example, in Figs. 35, 36 and 37. Preferably, a long deflection mirror 246 is provided between the processing surface 81 and the optics 245 in order to achieve a compact structure. The laser gun 23 is preferably turned in the prism 248 such that the processing tracks have the desired spacing from one another on the processing surface, this being shown in Fig. 35. The fixing of the laser gun can ensue with a strap retainer (not shown). An inventive arrangement 249 for removing the material eroded from the processing surface is attached close to the processing surface 81 over the entire line length, said arrangement 249 being capable of being provided with a glass plate 230 over the entire length and being shown in greater detail in Fig. 43b. In Fig. 43, a laser gun with the lenses 102 and 103 according to Fig. 4b and a beam path illustrated in Fig. 20 can be provided; however, all other types of inventive laser guns can also be used. Further, a plurality of laser radiation sources can be attached in such a flat bed arrangement in order to speed the processing procedure up. Inventively, a second laser radiation source with the appertaining optics and the arrangement 249 for removing the material eroded from the processing surface can be attached such opposite the illustrated arrangement that further processing tracks derive on the processing surface.

It lies within the framework of the invention that the rotating mirror can also be replaced by an oscillating mirror. It also lies in the scope of the invention that the rotating mirror can be replaced by two oscillating mirrors, whereby the oscillatory direction of the one mirror, called "mirror u", lies on the processing surface 81 in the direction referenced u, and whereby the oscillating direction of the other mirror called "mirror v", lies on the processing surface 81 in the direction referenced v.

An arrangement having oscillating mirrors is especially well-suited for fast incising of photo-voltaic cells, as was described in detail under Fig. 42. The cell to be incised is placed onto the table 247 with, for example, a loading device that is not shown in Fig. 43 and is brought into the correct position. The laser gun 23 is turned such that the desired spacings in the processing tracks arise in the two processing directions u and v. In a first processing event, for example, mirror u draws the contact lines, whereas mirror v undertakes the correct positioning of the contact line packets. In a second processing event, mirror v draws the bus bars, whereas mirror u undertakes the correct positioning of the line packets. In these processing events, the photo-voltaic cell is not moved. It lies within the scope of the invention that the table 247 can be replaced by a magazine (not shown) wherein a specific plurality of photo-voltaic cells are delivered for processing, that the processing of the respective cell ensues directly in the magazine, and that the processed cell is automatically removed from the magazine after the processing and transferred into a second magazine, whereby the next, unprocessed cell for processing moves forward to take the place of the removed cell.

As a result of the extremely high beam quality of the laser radiation source that derives due to the fiber laser working refraction-limited, a nearly parallel laser beam bundle can be generated, as shown in Fig. 43 between the optics 242 and rotating mirror 243 and as can also be seen in Fig. 4 between the lenses 57 and 61. Consequently, it is also possible to remove the optics 245, the rotating mirror 243 and the deflection mirror 246 in Fig. 43 and replace them

by a deflection mirror (not shown) that deflects the nearly parallel laser beam bundle emerging from the optics 242 in the direction of the processing surface 81 and onto an objective lens (not shown) having a short focal length that is implemented similar to the objective lenses 61, 103 or 112.

Deflection mirror and objective lens are inventively combined with one another to form a unit and slide back and forth on a guide rail (not shown) in the direction v, so that a plurality of parallel processing tracks corresponding to the plurality of channels in the laser radiation source are registered on the processing surface (81) similar to previously with the rotating mirror 243 and the optics 245.

Inventively, the guide rail is implemented as a bearing having very low friction, for example as an air bearing or as magnetic bearing. The drive of the unit composed of objective lens and deflection mirror in the direction v and back respectively ensues with a thrust into the corresponding direction that, for example, is carried out by a preferably contact-free electromagnetic system, whereby the energy acquired from the deceleration of the moving unit is partially re-employed for the drive. Parts of the guide rail, deflection mirror and objective lens are, for example, accommodated in a closed space that contains windows for the entry and the exit of the laser radiation and can be evacuated in order to reduce frictional losses. Drive and guide rail represent a linear drive for the unit composed of objective lens and deflection mirror.

It lies within the framework of the invention that the respective, true position of the moving unit can be determined for correction purposes via, for example, an optical reference track. An arrangement 249 serves for the removal of the material eroded from the processing surface (81). The advantage of such an arrangement is that it can be very cost-beneficially realized for long path lengths and high resolutions, and that it can be set to various formats by displacement of the one and/or other drive. A plurality of such units can also be arranged in parallel in order to increase the processing speed.

Fig. 43a shows a simplification of the arrangement according to Fig. 43 in that the two lenses 102 and 103 have been removed from the laser gun. Given a corresponding spacing of the laser gun from the deflection mirror 241, the divergent laser ray bundles emerging from the lens 101 are focused onto the processing surface 81 with the lenses 241 and 245 and generate the processing points B_1 through B_n that are identical to the processing points B_1' through B_n' in this case.

Fig. 43b shows the arrangement 249 for removing the material eroded from the processing surface in greater detail. The functioning has been described in detail in Fig. 34.

Fig. 44 shows a hollow bed arrangement for processing material with the inventive laser radiation source. Hohlbett arrangements are known; for example, two arrangements having hollow bed are described in the publication "Der Laser in der Druckindustrie" by Werner Hülsbuch [sic], Verlag W. Hülsbusch, Constanc, pages 461 and 562. The material to be processed with the processing surface 81 is located in a cylinder or, preferably, a part of a cylinder 236 having the radius R. This arrangement is referred to as hollow bed on whose axis a bearing 229 with a rotating mirror 233 is arranged. The rotating mirror can, for example, have one mirror face but can also be fashioned with a plurality of mirror faces and can be placed into rotation by a motor 234 and be arranged on a carriage (not shown) displaceable in the direction of the cylinder axis relative to the cylinder 236. An optics 231 belonging to an optical device and a mirror 232 are arranged as well on the carriage (not shown) in the proximity of the processing surface 81. Further, a deflection mirror 227 and the laser gun 23 as well as an arrangement 235 - close to the processing surface 81 - for removing the material eroded from the processing surface, which is described in greater detail in Fig. 34, are located on the carriage. The ray bundles 226 emerging from the laser gun generate processing points B_1 through B_n in an intermediate image plane 228 that are transmitted onto the processing surface 81 with the deflection mirror 227, the

mirror optics 231, 232 and the rotating mirror 233. Here, they generate the processing points B_1' through B_n'. The processing points B_1' through B_n' that form the processing spot generate processing tracks 224 (Figs. 35, 36 and 37) across the entire line length that are registered sharply focused over the entire line length as a result of the constant radius of the hollow bed. The advantage of the illustrated arrangement is comprised therein that a compact structure can be achieved. In particular, the illustrated arrangement enables a small angle δ between the axis of the ray bundle incident onto the rotating mirror 233 and the ray bundle that is reflected by the rotating mirror onto the processing surface, which is desirable for low distortion in the recording geometry on the processing surface. The laser gun is preferably seated in a prism (not shown) and is secured with a fastening strap (likewise not shown). The laser gun can be turned around its axis and can be displaced in axial direction. As a result of the rotation, the distance between the processing tracks can be modified, this being shown in Fig. 35. The spacing from the processing surface can be modified by the displacement. An inventive arrangement 235 for removing the material eroded from the processing surface is attached over the entire line length close to the processing surface 81, said arrangement 235 being capable of being fashioned similar to what is shown in Fig. 43b, whereby it is implemented curved corresponding to the radius R of the cylinder 236 and can be provided with a curved glass plate 237 (not shown) over the entire length, the functioning thereof having been described in detail under Fig. 34. In Fig.44, a laser gun having the lenses 102 and 103 according to Fig. 4b and a beam path shown in Fig. 20 are provided. However, all other types of the inventive laser gun can be utilized. Further, a plurality of laser radiation sources can also be attached in such a hollow bed arrangement in order to speed the processing event up. For example, a second rotating mirror and a second laser radiation source as well as a second arrangement 235 for removing the material eroded from the processing surface can be attached such opposite the illustrated arrangement that further processing tracks derive on the processing surface.

Fig. 44a shows a simplification of the arrangement according to Fig. 44, in that the two lenses 102 and 103 were removed from the laser gun. Given a corresponding spacing of the laser gun from the deflection mirror 227, the divergent laser ray beams emerging from the lens 101 are focused onto the processing surface 81 with the lens 231 and generate the processing points B_1 through B_n that are identical to the processing points B_1' through B_n' in this case.

Patent Claims

1. Laser radiation source, preferably for processing materials, characterized in that, for generating a laser radiation with high power density and high energy,
the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of tracks side-by-side; and in that
the laser beams (13) emerging from the outputs of the fiber lasers (2) impinge side-by-side in a plurality of tracks on a processing surface (81) (Figure 41).

2. Laser radiation source, preferably for processing materials, characterized in that, for generating a laser radiation with high power density and high energy,
the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged above one another in a plurality of planes; and in that
the laser beams (13) emerging from the outputs of the fiber lasers (2) are combined such that they impinge a processing surface (81) above one another in a plurality of planes (Figure 41).

3. Laser radiation source, preferably for processing materials, characterized in that, for generating a laser radiation with high power density and high energy,
the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of tracks side-by-side; and in that
the laser beams (13) emerging from the outputs of the fiber lasers (2) are combined such that they impinge onto a processing surface (81) in a point (Figure 41).

4. Laser radiation source, preferably for processing materials, characterized in that, for generating a laser radiation with high power density and high energy,

the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged above one another in a plurality of planes; and in that

the laser beams (13) emerging from the outputs of the fiber lasers (2) are combined and bundled such that they impinge onto a processing surface (81) in a point (Figure 41).

5. Laser radiation source, preferably for processing materials, characterized in that, for generating a laser radiation with high power density and high energy,

the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of tracks side-by-side and in a plurality of planes above one another; and in that

the laser beams (13) emerging from the outputs of the fiber lasers (2) are combined and bundled such that they impinge onto a processing surface (81) side-by-side in a plurality of tracks and above one another in a plurality of planes (Figure 41).

6. Laser radiation source, preferably for processing materials, characterized in that, for generating a laser radiation with high power density and high energy,

the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of tracks side-by-side and in a plurality of planes above one another; and in that

the laser beams (13) emerging from the outputs of the fiber lasers (2) are combined and bundled such that they impinge onto a processing surface side-by-side in a plurality of tracks in a plane (Figure 41).

7. Laser radiation source, preferably for processing materials, characterized in that, for generating a laser radiation with high power density and high energy,

the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of tracks side-by-side and in a plurality of planes above one another; and in that the laser beams (13) emerging from the outputs of the fiber lasers (2) are combined and bundled such that they impinge onto a processing surface (81) above one another in a plurality of planes (Figure 41).

8. Laser radiation source, preferably for processing materials, characterized in that, for generating a laser radiation with high power density and high energy,
the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of tracks side-by-side and in a plurality of planes above one another; and in that
the laser beams (13) emerging from the outputs of the fiber lasers (2) are combined and bundled such that they impinge onto a processing surface (81) in a point (Figure 41).

9. Laser radiation source, preferably for processing materials, characterized in that, for generating a laser radiation with high power density and high energy,
the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a bundle; and in that
the laser beams (13) emerging from the outputs of the fiber lasers (2) are combined and bundled such that they impinge onto a processing surface (81) in a point (Figure 41).

10. Laser radiation source, preferably for processing materials, comprising an optical unit (8) for shaping a laser beam on a processing surface (81), characterized in that, for generating a laser beam with high power density and high energy,
the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of tracks side-by-side; and in that

the laser beams (13) emerging from the outputs of the fiber lasers (2) are combined and bundled such by the optical unit that the laser beams (13) impinge side-by-side in a plurality of tracks onto the processing surface (81) (Figure 29, Figure 41).

11. Laser radiation source, preferably for processing materials, comprising an optical unit (8) for shaping a laser beam on a processing surface (81), characterized in that, for generating a laser beam with high power density and high energy,

the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged above one another in a plurality of planes; and in that

the laser beams (13) emerging from the outputs of the fiber lasers (2) are combined and bundled such by the optical unit (8) that they impinge onto the processing surface (81) above one another in a plurality of planes (Figure 29, Figure 41).

12. Laser radiation source, preferably for processing materials, comprising an optical unit (8) for shaping a laser beam on a processing surface (81), characterized in that, for generating a laser beam with high power density and high energy,

the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of tracks side-by-side Figure 29, Figure 41); and in that

the laser beams (13) emerging from the outputs of the fiber lasers (2) are combined and bundled such with the optical unit that the rays impinge onto a processing surface (81) in a point (201, Figure 31).

13. Laser radiation source, preferably for processing materials, comprising an optical unit (8) for shaping a laser beam on a processing surface (81), characterized in that, for generating a laser radiation with high power density and high energy,

the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of planes above one another; and in that

the laser beams (13) emerging from the outputs of the fiber lasers (2) are combined and bundled such with the optical unit (8) that the laser beams (13) impinge onto the processing surface (81) in a point (201, Figure 31).

14. Laser radiation source, preferably for processing materials, comprising an optical unit (8) for shaping a laser beam on a processing surface (81), characterized in that, for generating a laser radiation with high power density and high energy,

the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of tracks (Figure 29, Figure 41) side-by-side and in a plurality of planes above one another; and in that

the laser beams (13) emerging from the outputs of the fiber lasers (2) are combined and bundled such with the optical unit (8) that the laser beams (13) impinge onto the processing surface (81) side-by-side in a plurality of tracks (Figure 29, Figure 41) and above one another in a plurality of planes.

15. Laser radiation source, preferably for processing materials, comprising an optical unit (8) for shaping a laser beam on a processing surface (81), characterized in that, for generating a laser radiation with high power density and high energy,

the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of tracks (Figure 29, Figure 41) side-by-side and in a plurality of planes above one another; and in that

the laser beams (13) emerging from the outputs of the fiber lasers (2) are combined and bundled such with the optical unit (8) that the laser beams (13) impinge onto the processing surface side-by-side in a plurality of tracks (Figure 29, Figure 41) in a plane.

16. Laser radiation source, preferably for processing materials, comprising an optical unit (8) for shaping a laser beam on a processing surface (81), characterized in that, for generating a laser radiation with high power density and high energy,
the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of tracks (Figure 29, Figure 41) side-by-side and in a plurality of planes above one another; and in that
the laser beams (13) emerging from the outputs of the fiber lasers (2) are combined and bundled such with the optical unit (8) that the laser beams impinge onto the processing surface (81) above one another in a plurality of planes (Figure 41).

17. Laser radiation source, preferably for processing materials, comprising an optical unit (8) for shaping a laser beam on a processing surface (81), characterized in that, for generating a laser radiation with high power density and high energy,
the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of tracks side-by-side (Figure 29, Figure 41) and in a plurality of planes above one another; and in that
the laser beams (13) emerging from the outputs of the fiber lasers (2) are combined and bundled such with the optical unit (8) that the laser beams (13) impinge onto the processing surface (81) in a point (201, Figure 31).

18. Laser radiation source, preferably for processing materials, comprising an optical unit (8) for shaping a laser beam on a processing surface (81), characterized in that, for generating a laser radiation with high power density and high energy,
the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a bundle; and in that

the laser beams (13) emerging from the outputs of the fiber lasers (2) that [sic] are combined and bundled such with the optical unit (8) that the laser beams (13) impinge onto the processing surface (81) in a point (201, Figure 31).

19. Laser radiation source, preferably for processing materials, comprising an optical unit (8) for shaping a laser beam on a processing surface (81), characterized in that, for generating a laser beam with high power density and high energy,
the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of tracks (Figure 29, Figure 41) side-by-side; in that
the optical unit (8) for shaping the laser radiation comprises a modulation unit (Figure 41, Figure 19, Figure 19a) onto whose input the laser beams (13) emerging from the outputs of the fiber lasers (2) are directed and with which the individual laser beams (13) can be respectively modulated; and in that
the laser beams (13) emerging from the modulation unit (Figure 41, Figure 19, Figure 19a) are combined and bundled such that the laser beams (13) impinge side-by-side in a plurality of tracks (Figure 29, Figure 41) onto the processing surface (81).

20. Laser radiation source, preferably for processing materials, comprising an optical unit (8) for shaping a laser beam on a processing surface (81), characterized in that, for generating a laser beam with high power density and high energy,
the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged above one another in a plurality of planes; in that
the optical unit (8) for shaping the laser radiation comprises a modulation unit (Figure 41, Figure 19, Figure 19a) onto whose input the laser beams (13) emerging from the outputs of the fiber lasers (2) are directed and with which the individual laser beams (13) can be respectively modulated; and in that

the laser beams (13) emerging from the outputs of the modulation unit (Figure 4a, Figure 19, Figure 19a) are combined and bundled such that they impinge onto the processing surface (81) above one another in a plurality of planes.

21. Laser radiation source, preferably for processing materials, comprising an optical unit (8) for shaping a laser beam on a processing surface (81), characterized in that, for generating a laser beam with high power density and high energy,

the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of tracks side-by-side (Figure 29, Figure 41); in that

the optical unit (8) for shaping the laser radiation comprises a modulation unit (Figure 41, Figure 19, Figure 19a) onto whose input the laser beams (13) emerging from the outputs of the fiber lasers (2) are directed and with which the individual laser beams (13) can be respectively modulated; and in that

the laser beams (13) emerging from the modulation unit (Figure 4a, Figure 19, Figure 19a) are combined and bundled such with the optical unit (8) that the rays impinge onto a processing surface (81) in a point (201, Figure 31).

22. Laser radiation source, preferably for processing materials, comprising an optical unit (8) for shaping a laser beam on a processing surface (81), characterized in that, for generating a laser radiation with high power density and high energy,

the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of planes above one another; in that

the optical unit (8) for shaping the laser radiation comprises a modulation unit (Figure 41, Figure 19, Figure 19a) onto whose input the laser beams (13) emerging from the outputs of the fiber lasers (2) are directed and with which the individual laser beams (13) can be respectively modulated; and in that

the laser beams (13) emerging from the modulation unit (Figure 4a, Figure 19, Figure 19a) are combined and bundled such with the optical unit (8) that the

laser beams (13) impinge onto the processing surface (81) in a point (201, Figure 31).

23. Laser radiation source, preferably for processing materials, comprising an optical unit (8) for shaping a laser beam on a processing surface (81), characterized in that, for generating a laser radiation with high power density and high energy,
the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of tracks (Figure 29, Figure 41) side-by-side and in a plurality of planes above one another; in that
the optical unit (8) for shaping the laser radiation comprises a modulation unit (Figure 41, Figure 19, Figure 19a) onto whose input the laser beams (13) emerging from the outputs of the fiber lasers (2) are directed and with which the individual laser beams (13) can be respectively modulated; and in that
the laser beams (13) emerging from the modulation unit (Figure 4a, Figure 19, Figure 19a) are combined and bundled such with the optical unit (8) that the laser beams (13) impinge onto the processing surface (81) side-by-side in a plurality of tracks (Figure 29, Figure 41) and above one another in a plurality of planes.

24. Laser radiation source, preferably for processing materials, comprising an optical unit (8) for shaping a laser beam on a processing surface (81), characterized in that, for generating a laser radiation with high power density and high energy,
the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of tracks side-by-side and in a plurality of planes above one another; in that
the optical unit (8) for shaping the laser radiation comprises a modulation unit (Figure 41, Figure 19, Figure 19a) onto whose input the laser beams (13) emerging from the outputs of the fiber lasers (2) are directed and with which the individual laser beams (13) can be respectively modulated; and in that

the laser beams (13) emerging from the modulation unit (Figure 4a, Figure 19, Figure 19a) are combined and bundled such with the optical unit (8) that the laser beams (13) impinge onto the processing surface side-by-side in a plurality of tracks (Figure 29, Figure 41).

25. Laser radiation source, preferably for processing materials, comprising an optical unit (8) for shaping a laser beam on a processing surface (81), characterized in that, for generating a laser radiation with high power density and high energy,

the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of tracks side-by-side and in a plurality of planes above one another; in that

the optical unit (8) for shaping the laser radiation comprises a modulation unit (Figure 41, Figure 19, Figure 19a) onto whose input the laser beams (13) emerging from the outputs of the fiber lasers (2) are directed and with which the individual laser beams (13) can be respectively modulated; and in that

the laser beams (13) emerging from the modulation unit (Figure 4a, Figure 19, Figure 19a) are combined and bundled such with the optical unit (8) that the laser beams (13) impinge onto the processing surface (81) above one another in a plurality of planes.

26. Laser radiation source, preferably for processing materials, comprising an optical unit (8) for shaping a laser beam on a processing surface (81), characterized in that, for generating a laser radiation with high power density and high energy,

the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a plurality of tracks side-by-side (Figure 29, Figure 41) and in a plurality of planes above one another; in that

the optical unit (8) for shaping the laser radiation comprises a modulation unit (Figure 41, Figure 19, Figure 19a) onto whose input the laser beams (13)

emerging from the outputs of the fiber lasers (2) are directed and with which the individual laser beams (13) can be respectively modulated; and in that the laser beams (13) emerging from the modulation unit (Figure 4a, Figure 19, Figure 19a) are combined and bundled such with the optical unit (8) that the laser beams (13) impinge onto the processing surface (81) in a point (201, Figure 31).

27. Laser radiation source, preferably for processing materials, comprising an optical unit (8) for shaping a laser beam on a processing surface (81), characterized in that, for generating a laser radiation with high power density and high energy,
the laser light source (1) comprises a plurality of directly modulatable, diode-pumped fiber lasers (2) whose outputs are arranged in a bundle; in that
the optical unit (8) for shaping the laser radiation comprises a modulation unit (Figure 41, Figure 19, Figure 19a) onto whose input the laser beams (13) emerging from the outputs of the fiber lasers (2) are directed and with which the individual laser beams (13) can be respectively modulated; and in that
the laser beams (13) emerging from the modulation unit (Figure 4a, Figure 19, Figure 19a) are combined and bundled such with the optical unit (8) that the laser beams (13) impinge onto the processing surface (81) in a point (201, Figure 31).

28. Laser radiation source according to one of the claims 1 through 27, characterized in that the laser output of at least one of the fiber lasers (20 comprises a passive fiber (28) as laser output.

29. Laser radiation source according to one of the claims 1 through 27, characterized in that at least one of the fiber lasers (2) comprises a plurality of passive fibers (28, Figure 15) as laser outputs.

30. Laser radiation source according to one of the claims 1 through 27, characterized in that at least one laser output is provided to which a plurality of fiber lasers (2) are connected.

31. Laser radiation source according to one of the claims 10 through 30, characterized in that
the outputs (13) of the fiber lasers (2) are provided with a terminator (26, 94) with which the fiber lasers (2) are connected to the optical unit (8); and in that the optical unit (8) for shaping the laser beam comprises mounts (29) at the beam entry (9) that accept the terminators (26, 94) of the lasers such that the output rays of the lasers at the beam exit (10) of the optical unit (8) for shaping the beam impinge on the processing surface (81).

32. Laser radiation source according to claim 31, characterized in that
the terminator (26, 94) is composed of an oblong housing (132) that comprises a through cylindrical opening (130) extending in axial direction for the acceptance of the optical fibers (5, 28) and one or more outer fits (134) as reference surface or reference surfaces for the acceptance in the mounts (29);
the optical fiber (5, 28) is accepted and guided within the housing at that end of the housing (132) at which the optical fiber (5, 28) enters;
a positive lens (133) having a short focal length is secured to the other end of the housing (132);
the end of the optical fiber (5, 28) within the through cylindrical opening (130) extending in axial direction as well as the positive lens (133) are aligned and fixed relative to one another; and in that
the exit point of the radiation from the optical fiber (5, 28) lies approximately in the focal point of the positive lens (133) and the ray bundle of the laser beam (144) emerging from the positive lens is aligned defined with respect to the fit or fits (134).

33. Laser radiation source according to claim 32, characterized in that the symmetry axis of the fit or fits (134) coincides with the symmetry axis of the fiber (5, 28).

34. Laser radiation source according to claim 32 or 33, characterized in that the symmetry axis of the fit or fits (134) coincides with the symmetry axis of the positive lens (133).

35. Laser radiation source according to one of the claims 32 through 34, characterized in that the symmetry axis of the fit surfaces coincides with the symmetry axis of the laser beam (144) emerging from the positive lens (133).

36. Laser radiation source according to one of the claims 32 through 35, characterized in that the distance from the end of the fiber (5, 28) to the positive lens (133) is selected such that the laser beam (144) emerging from the positive lens (133) is divergent outside the terminator (26, 94).

37. Laser radiation source according to one of the claims 32 through 36, characterized in that the distance from the end of the fiber (5, 28) to the positive lens (133) is selected such that the laser beam (144) emerging from the positive lens (133) is convergent outside the terminator (26, 94) at a predetermined distance from the positive lens (133).

38. Laser radiation source according to one of the claims 32 through 37, characterized in that the distance from the end of the fiber to the positive lens (133) is selected such that the laser beam (144) emerging from the positive lens (133) is nearly parallel outside the terminator (26, 94) at a predetermined distance from the positive lens (133).

39. Laser radiation source according to one of the claims 32 through 38, characterized in that a plurality of adjustment screws distributed over the circumference are provided within the housing (132), the optical fiber (5, 28) being finely adjustable therewith in the housing (132).

40. Laser radiation source according to one of the claims 32 through 39, characterized in that further adjustment screws (136) are provided at that end of the terminator (26, 94) at which the optical fiber (5, 28) enters.

41. Laser radiation source according to one of the claims 32 through 38, characterized in that small balls (137) of metal or metallized glass are employed for the adjustment, these being fixed after the adjustment.

42. Laser radiation source according to one of the claims 32 through 41, characterized in that

the connections between the optical fiber (5, 28) and the housing (132), the positive lens (133) and the housing (132) as well as the adjustment screws (135) and (136) or balls (137) are hermetically closed; and in that

the cavity (143) that remains within the housing (132) is preferably filled with protective atmosphere.

43. Laser radiation source according to one of the claims 32 through 42, characterized in that the seal locations at the housing (132) are glued, soldered or welded.

44. Laser radiation source according to one of the claims 32 through 43, characterized in that the end of the optical fiber (5, 28) is stripped of its cladding (17) in its end region and is preferably roughened at its outside surface.

45. Laser radiation source according to one of the claims 32 through 44, characterized in that the end of the optical fiber (5, 28) is mirrored such that the pump radiation is reflected; and in that the laser radiation is partly allowed to pass.

46. Laser radiation source one of the claims 32 through 45, characterized in that the terminator (26, 94) is conically fashioned (Figure 7) at its front end in the region of the positive lens (133).

47. Laser radiation source according to one of the claims 32 through 46, characterized in that

the terminator (94) comprises a rectangular crossection in the region of the fit or fits (134); and in that

two outside surfaces extending in longitudinal direction trapezoidally approach one another in the region of the fit or fits (134) (Figure 10, Figure 10a, Figure 10b).

48. Laser radiation source according to one of the claims 32 through 46, characterized in that

the terminator (26) comprises a quadratic or rectangular crossection in the region of the fit or fits; and in that

the outside surfaces extending in longitudinal direction proceed parallel to one another in the region of the fit or fits (Figure 9, Figure 9a).

49. Laser radiation source according to one of the claims 32 through 46, characterized in that the terminator (26) comprises a trapezoidal crossection in the region of the fit or fits (134) (Figure 11).

50. Laser radiation source according to one of the claims 32 through 46, characterized in that the terminator (26) comprises a triangular crossection in the region of the fit or fits (134) (Figure 11a).

51. Laser radiation source according to one of the claims 32 through 46, characterized in that the terminator (26) comprises a hexagonal crossection in the region of the fit or fits (134) (Figure 12).

52. Laser radiation source according to one of the claims 32 through 46, characterized in that the terminator (26, 94) is cylindrically or conically fashioned in the region of the fit or fits (134).

53. Laser radiation source according to claim 31, characterized in that the mounts (29) comprise fitting surfaces for the fit or fits (134) of the terminators (26, 94) that are arranged such that the symmetry axes of the laser beams emerging from the positive lenses (133) of the terminators (26, 94) are arranged in at least one track and/or one plane.

54. Laser radiation source according to claim 53, characterized in that the fitting surfaces of the mounts (29) for the fit or fits (134) of the terminators (26, 94) for the individual tracks and levels are arranged such that the symmetry axes of the laser beams (144) emerging from the positive lenses (133) of the terminators (26, 94) for the individual tracks as well as for the individual planes proceeds at an angle relative to one another.

55. Laser radiation source according to claim 53, characterized in that the fitting surfaces of the mounts (29) for the fit or fits (134) of the terminators (26, 94) for the individual tracks are arranged such that the symmetry axes of the laser beams emerging from the positive lenses (133) of the terminators (26, 94) proceed at an angle relative to one another; and in that the fitting surfaces of

the mounts (29) for the fit or fits (134) of the terminators (26, 94) for the individual planes are arranged such that the symmetry axes of the laser beams emerging from the positive lenses (133) of the terminators (26, 94) are parallel to one another.

56. Laser radiation source according to claim 53, characterized in that the fitting surfaces of the mounts (29) for the fit or fits (134) of the terminators (26, 94) for the individual planes are arranged such that the symmetry axes of the laser beams emerging from the positive lenses (133) of the terminators (26, 94) proceed at an angle relative to one another; and in that the fitting surfaces of the mounts (29) for the fit or fits (134) of the terminators (26, 94) for the individual tracks are arranged such that the symmetry axes of the laser beams emerging from the positive lenses (133) of the terminators (26, 94) are parallel to one another.

57. Laser radiation source according to claim 31, characterized in that the fitting surfaces of the mounts (29) for the fit or fits (134) of the terminators (26, 94) are arranged such that the symmetry axes of the laser beams emerging from the positive lenses (133) of the terminators (26, 94) are arranged in a bundle (Figure 30); and in that the symmetry axes of the laser beams emerging from the positive lenses (133) of the terminators (26, 94) proceed at an angle relative to one another.

58. Laser radiation source according to claim 53 or 57, characterized in that the mounts (29) comprise fitting surfaces for the fit or fits (134) of the terminators (26, 94) that are arranged such that the symmetry axes of the laser beams emerging from the positive lenses (133) of the terminators (26, 94) are parallel to one another.

59. Laser radiation source according to one of the claims 19 through 58, characterized in that the modulation unit (Figure 4a, Figure 19, Figure 19a) comprises one or more separate modulators.

60. Laser radiation source according to one of the claims 19 through 59, characterized in that the modulation unit (Figure 4a, Figure 19, Figure 19a) is composed of one or more multi-channel modulators (34).

61. Laser radiation source according to one of the claims 19 through 60, characterized in that electrooptical modulators and/or electrooptical deflectors (168) are utilized.

62. Laser radiation source according to claim 19 through 60, characterized in that acousto-optical modulators and/or acousto-optical deflectors (34) are utilized.

63. Laser radiation source according to one of the claims 10 through 62, characterized in that the optical unit (8) for shaping the laser beam in the region between the radiation entry)9) and the radiation exit (10) contains means for merging the individual laser beams (13).

64. Laser radiation source according to one of the claims 10 through 63, characterized in that, for merging the individual laser beams, means are provided for reducing the spacing of the symmetry axes of the ray bundles (rays of the laser outputs) (144) emerging from the positive lense (133) of the terminators (26, 94) in the direction of the tracks and/or in the direction of the planes.

65. Laser radiation source according to one of the claims 10 through 64, characterized in that at least one lens is provided as means for decreasing the spacing of the symmetry axes of the beams of the laser outputs (144).

66. Laser radiation source according to claim 65, characterized in that two positive lenses (191, 192) are provided as means for decreasing the spacing of the symmetry axes of the beams of the laser outputs (144).

67. Laser radiation source according to claim 65, characterized in that a positive lens (202) and a dispersive lens (203) are provided as means for decreasing the spacing of the symmetry axes of the beams of the laser outputs (144).

68. Laser radiation source according to claim 65, characterized in that spherical lenses (191, 192) or cylindrical lenses (202, 203) are provided.

69. Laser radiation source according to one of the claims 66 through 68, characterized in that the spacing of the two lenses amounts to approximately the same as the sum of their two focal lengths.

70. Laser radiation source according to one of the claims 66 through 69, characterized in that the spacing of the two lenses is set such that the rays bundles overlap in the modulator (34).

71. Laser radiation source according to the claims 10 through 70, characterized in that mirrors and/or lenses and/or wavelength-dependent and/or polarization-dependent elements are employed as means for merging the rays of the beams of the laser outputs (133).

72. Laser radiation source according to claim 71, characterized in that a wavelength-dependent element is employed for merging the beams of at least two laser outputs.

73. Laser radiation source according to claim 72, characterized in that a filter (37) that allows the radiation of one of the laser outputs to pass and reflects the radiation of the other laser output is employed as wavelength-dependent element.

74. Laser radiation source according to claim 71, characterized in that a polarization-dependent element is employed for merging the beams of at least two laser outputs having polarized radiation.

75. Laser radiation source according to claim 74, characterized in that a polarization-dependent mirror that allows the polarization-directed radiation of one of the laser outputs to pass and reflects the polarization-directed radiation of the other laser output is employed as polarization-dependent element.

76. Laser radiation source according to claim 71, characterized in that a strip mirror (46) that allows the rays of the laser outputs from a first direction to pass and reflects the rays of the laser outputs from a second direction is employed for merging the rays of at least two laser outputs.

77. Laser radiation source according to one of the claims 63 through 76, characterized in that the means for merging the rays are arranged preceding and or [sic] following the modulation unit (Figure 4a) in beam direction.

78. Laser radiation source according to claim 63, characterized in that one or more single-channel or multi-channel deflectors (34) or one-channel or multi-channel electrooptical deflectors are provided as means for merging the beams within the modulation unit (Figure 4a, Figure 19, Figure 19a, Figure 36, Figure 36a, Figure 37).

79. Laser radiation source according to claim 78, characterized in that the acousto-optical deflectors (34) are operated with one frequency per channel for generating one processing point per channel.

80. Laser radiation source according to claim 78, characterized in that the acousto-optical deflectors (34) are operated with a mix of a plurality of frequencies per channel for generating a plurality of processing points per channel.

81. Laser radiation source according to one of the claims 78 through 80, characterized in that the acousto-optical deflectors (34) within the modulation unit (Figure 4a, Figure 19, Figure 19a) are employed for merging the beams of the laser outputs and for the modulation of the individual laser beams.

82. Laser radiation source according to one of the claims 10 through 81, characterized in that the optical unit (8) for shaping the laser beam contains a transmission unit for the transmission of the laser beams emerging from the terminators onto the processing surface (81), said transmission unit containing at least one lens (165, 186, 197).

83. Laser radiation source according to one of the claims 10 through 82, characterized in that the transmission unit comprises at least one positive lens and at least one dispersing lens (101).

84. Laser radiation source according to one of the claims 10 through 81, characterized in that the transmission unit comprises at least one arced mirror (121), one concave mirror (115) and a positive lens (112).

85. Laser radiation source according to one of the claims 10 through 81, characterized in that the transmission unit comprises a concave mirror (115), a dispersing lens and a positive lens.

86. Laser radiation source according to one of the claims 10 through 81, characterized in that the transmission unit comprises at least one concave mirror (115) and a plurality of positive lenses.

87. Laser radiation source according to one of the claims 82 through 86, characterized in that a transparent plate (117) is provided between the concave mirror (115) and the processing surface (81).

88. Laser radiation source according to one of the claims 82 through 87, characterized in that the transmission unit contains at least one deflection mirror.

89. Laser radiation source according to one of the claims 82 through 88, characterized in that the transmission unit is fashioned two-stage, whereby the first stage demagnifies the ray bundle (144) formed in the positive lens (133) of the terminators (26, 94) and transmits them into an intermediate image plane (183), and the second stage transmits the ray bundles of the intermediate image plane (183) demagnified onto the processing surface (81).

90. Laser radiation source according to one of the claims 82 through 89, characterized in that

a first transmission unit with a positive lens (55) and a positive lens (56) with a shorter focal length than the positive lens (55) is arranged in the beam path (Figure 20) following the positive lenses (133) of the terminators (26, 94) that are arranged in one or more planes and in one or more tracks 1 through n, the ray bundles (144) that emerge from the positive lenses (133) of the terminators (26, 94) and whose symmetry axes in the individual tracks proceed approximately parallel to one another being deflected such by said first transmission unit that the rays cross at a location (184);

in that the deflection of the positive lens (55) is reversed by the positive lens (56), whereby an image of the ray bundles (144) emerging from the positive

lenses (133) of the terminators (26) that is demagnified in the ratio of the focal lengths of the lenses (55 and 56) arises in an intermediate image plane (183) following in the beam path, and the ray bundles exhibit a divergence angle that is increased in the ratio of the focal lengths; and

in that a second transmission unit having a positive lens (57) and a positive lens (61) with a shorter focal length than the positive lens (57) is arranged in the beam path following the intermediate image plane (183), the demagnified image of the ray bundle from the intermediate image plane (183) being transmitted onto the processing surface (81) with said second transmission unit, whereby each ray bundle emerging from the positive lenses (133) of the terminators (26) generates a processing point (B_1 through B_n).

91. Laser radiation source according to claim 90, characterized in that the distance between the lens (55) and the crossing point (184) is approximately equal to the focal length of the lense (55);

in that the distance between the intermediate image plane (183) and the lens (57) as well as the distance between the crossing point (187) and the lens (57) is approximately equal to the focal length of the lens (57);

in that the distance between the crossing point (187) and the lens (61) as well as between the processing surface (81) and the lens (61) is approximately equal to the focal length of the lens (61); and

in that the spacings of the lenses are selected such that the symmetry axes of the ray bundles that impinge onto the processing surface (81) are approximately parallel to one another.

92. Laser radiation source according to claim 82, characterized in that a transmission unit with a dispersing lens (101) and two positive lenses (102 and 103) is arranged in the beam path (Figure 21) following the positive lenses (133) of the terminators (94) that are arranged in one or more planes and in one or more tracks 1 through n (Figure 21, Figure 24, Figure 32, Figure 33), the ray bundles (144) whose symmetry axes in the individual tracks proceed at an angle relative to one another and which emerge from the positive lenses (133) of the

terminators (94) being deflected and widened such by said transmission unit that the beams cross in the lens (102), whereby the divergent rays bundles (144) are aligned approximately parallel by the lens (102) and respectively leave the lens (102) at an angle; and

in that a lens with which the approximately parallel ray bundles are focussed onto the processing surface (81) is arranged in the beam path following the lens (102), whereby each ray bundle emerging from the positive lenses (133) of the terminators (26, 94) generates a processing point (B_1 through B_n).

93. Laser radiation source according to claim 92, characterized in that the focal length of the dispersing lens (101) is significantly smaller than that of the positive lens (102);

in that the spacing of the lenses (103) and (102) is approximately equal to the focal length of the lens (103); and

in that the distance between the processing surface (81) and the lens (103) is approximately equal to the focal length of the lens (103), whereby the spacings of the lenses are selected such that the symmetry axes of the ray bundles that impinge onto the processing surface (81) are approximately parallel to one another.

94. Laser radiation source according to claim 82, characterized in that a transmission unit with an arced mirror (121), a concave mirror (115) and a positive lens (112) is arranged in the beam path (Figure 22) following the positive lenses (133) of the terminators (94), which are arranged in one or more planes and in one or more tracks 1 through n (Figure 21, Figure 24, Figure 32, Figure 33), the ray bundles (144) whose symmetry axes in the individual tracks proceed at an angle relative to one another and which emerge from the positive lenses (133) of the terminators (94) being deflected and widened such by said transmission unit that the ray bundles cross on the concave mirror (115), whereby the divergent rays bundles (144) are aligned approximately parallel by the concave mirror (115) and respectively leave the hollow mirror at an angle; and

in that a lens (112) with which the approximately parallel ray bundles are focussed onto the processing surface (81) is arranged in the beam path following the concave mirror (115), whereby each ray bundle emerging from the positive lenses (133) of the terminators (26, 94) generates a processing point (B_1 through B_n).

95. Laser radiation source according to claim 94, characterized in that the focal length of the arced mirror (121) is significantly smaller than that of the concave mirror (115);
in that the distance between the concave mirror (115) and the arced mirror (121) is approximately equal to the sum of the focal lengths of concave mirror and arced mirror; and
in that the distance between the processing surface (81) and the lens (112) is approximately equal to the focal length of the lens (112), whereby the spacings of the lenses and mirrors are selected such that the symmetry axes of the ray bundles that impinge onto the processing surface (81) are approximately parallel to one another.

96. Laser radiation source according to one of the claims 89 through 95, characterized in that the symmetry axes of the ray bundles (144) emerging from the positive lenses (133) of the terminators (26) proceed approximately parallel to one another in the individual planes.

97. Laser radiation source according to one of the claims 89 through 95, characterized in that the symmetry axes of the ray bundles (144) emerging from the positive lenses (133) of the terminators (26) proceed at an angle relative to one another in the individual planes.

98. Laser radiation source according to one of the claims 82 through 86 or 89 through 96, characterized in that the lenses are fashioned as lens systems.

99. Laser radiation source according to one of the claims 84 through 88 or 94 or 95, characterized in that the mirrors (115, 121) comprise spherical and/or aspherical surfaces.

100. Laser radiation source according to one of the claims 82 through 99, characterized in that the transmission unit contains at least one deflection mirror.

101. Laser radiation source according to one of the claims 84 through 88 or 94 through 100, characterized in that at least one of the mirrors is made of metal.

102. Laser radiation source according to one of the claims 82 through 101, characterized in that the transmission unit comprises an interchangeable objective (61, 103, 112).

103. Laser radiation source according to one of the claims 87 through 102, characterized in that the transparent plate (117) is an optical correction plate.

104. Laser radiation source according to one of the claims 31 through 103, characterized in that the ray bundles (144) emerging from the positive lenses (133) of the terminators (26, 94) comprise an exit cone that can be set such by the spacing of the positive lens (133) from the fiber end within the terminators (26, 94) that an optimum sharpness derives for the processing points B_1 through B_n on the processing surface (81).

105. Laser radiation source according to one of the claims 10 through 104, characterized in that the optical unit (8) for shaping the laser beam on the processing surface (81) comprises means for neutralizing laser radiation that should not produce a processing effect on the processing surface (81).

106. Laser radiation source according to claim 105, characterized in that means for defocussing the unwanted radiation are provided in the beam path for neutralizing the unwanted radiation that should not produce a processing effect on the processing surface (81), whereby the defocussed radiation impinges the processing surface (81) without producing a processing effect.

107. Laser radiation source according to one of the claims 10 through 105, characterized in that an intercept arrangement (73) is provided for neutralizing the laser radiation that should not produce a processing effect on

the processing surface (81), said intercept arrangement (73) comprising a deflection mirror (74, 97, 121) arranged in the beam path with which the unwanted laser radiation that should produce no processing effect on the processing surface is kept away from the processing surface (81).

108. Laser radiation source according to claim 107, characterized in that the deflection mirror (74, 97) is fabricated of metal.

109. Laser radiation source according to one of the claims 10 through 105, characterized in that an intercept arrangement is provided for neutralizing the laser radiation that should not produce a processing effect on the processing surface (81), said intercept arrangement comprising a polarization-dependent mirror with which the unwanted laser radiation that should not produce a processing effect on the processing surface is kept away from the processing surface (81).

110. Laser radiation source according to one of the claims 105 or 107 through 109, characterized in that a sump into which the unwanted radiation is conducted is provided for intercepting the unwanted radiation.

111. Laser radiation source according to claim 110, characterized in that the sump is composed of a medium that absorbs the unwanted radiation in that the energy of the radiation is converted into heat.

112. Laser radiation source according to claim 110 or 111, characterized in that the sump is fashioned as a heat exchanger.

113. Laser radiation source according to claim 107 or 108, characterized in that the arced mirror (121) and the deflection mirror (97) are fabricated of one piece.

114. Laser radiation source according to claim 113, characterized in that the arced mirror (121) is also fashioned as deflection mirror for the unwanted radiation.

115. Laser radiation source according to one of the claims 10 through 114, characterized in that the optical surfaces are anti-bloomed.

116. Laser radiation source according to one of the claims 10 through 115, characterized in that the optical components are glued into their mounts.

117. Laser radiation source according to one of the claims 10 through 115, characterized in that the optical components are soldered into their mounts.

118. Laser radiation source according to one of the claims 10 through 117, characterized in that at least one of the optical components is fabricated of a material, particularly sapphire, that has a higher thermal conductivity than glas.

119. Laser radiation source according to one of the claims 1 through 118, characterized in that the outputs (13) of the fiber lasers (2) are combined in a receptacle, whereby the receptacle is fashioned such that the laser radiation is directed onto the processing surface (81).

120. Laser radiation source according to claim 119, characterized in that the receptacle is fashioned multi-part for the adaptation of the optical unit (8), whereby a first part of the receptacle is fashioned as housing (35, 93).

121. Laser radiation source according to claim 120, characterized in that the optical unit (8) contains means for merging the individual laser beams (37), said means being arranged within the housing (35, 93).

122. Laser radiation source according to claim 121, characterized in that the housing (35, 93) contains the mounts (29) for the terminators (26, 94), these being arranged and aligned such that the individual laser beams are merged on the processing surface (81).

123. Laser radiation source according to claim 122, characterized in that means are provided in the housing (35, 93) for diminishing the spacing of the symmetry axes of the ray bundles (46, 191, 192, 202, 203) emerging from the positive lenses (133) of the terminators (26, 94).

124. Laser radiation source according to claim 123, characterized in that a cylindrical opening (48) is provided in the housing (36, 93) for an interchangeable modulator housing (172) that can be adjusted and fixed within

the cylindrical opening by turning and that comprises electrical terminals (181) at its directed toward the outside that are connected to a control electronics and to a line arrangement (171) for the electrical drive of the modulator and/or deflector (34, 168); and

in that the face end of the modulator housing directed into the interior (44, 111) of the housing (35, 93) comprises a holder for the modulator and/or deflector (34, 168) and the inside thereof contains the line arrangement (171), whereby the line arrangement projects into the interior (44, 111) from the inside of the modulator housing (172) through the face end directed to the interior of the housing (35, 93) and is electrically connected to the modulator.

125. Laser radiation source according to claim 124, characterized in that the housing (35, 93) comprises a plurality of cylindrical openings (48) for a plurality of modulator housings (172).

126. Laser radiation source according to claim 119, characterized in that a second part of the receptacle for the adaptation of the optical unit (8) attaches to the housing in the direction of the beam path, said second part containing the transmission unit and being fashioned as tube (51, 95, 113) that is centered by a bore (47) arranged at the beam exit side of the housing (35, 93) and is flanged to the housing (35, 93).

127. Laser radiation source according to claim 126, characterized in that an arrangement (73, 86) for the interception and neutralization of the laser radiation that should not produce a processing effect on the processing surface is laterally flanged to the tube (51, 95, 113).

128. Laser radiation source according to claim 127, characterized in that an arrangement (82) for removal of the material eroded from the processing surface (81) is provided between the beam exit from the transmission unit at the end of the tube (51, 95, 113) and the processing surface (81).

129. Laser radiation source according to claim 128, characterized in that the tube (51, 95, 113) can be rotated around its axis defined by the objective lens (61, 103, 112) and/or is seated displaceable in its longitudinal direction.

130. Laser radiation source according to one of the claims 126 through 129, characterized in that
a plate (114) that accepts a concave mirror (115) and contains a bore (122) through which the laser radiation enters from the housing into the tube is provided at that end of the tube (113) that is attached to the housing (93);
in that an arced mirror (121) onto which the laser radiation entering into the tube through the opening (122) is incident is arranged at the other end of the tube to which the arrangement (73, 86) for intercepting and neutralizing the laser radiation is flanged, whereby the laser radiation that is intended to produce a processing effect is reflected onto the concave mirror (115) and the unwanted laser radiation that should not produce any processing effect is redirected with the arced mirror (121) or a plane mirror (97) into the arrangement (73, 86) for intercepting and neutralizing the laser radiation; and
in that an objective (112) onto which the laser radiation that should produce a processing effect is directed with the concave mirror (115) is provided at that end of the tube facing toward the processing surface (81), whereby the objective generates a processing spot (24) on the processing surface (81).

131. Laser radiation source according to one of the claims 126 through 129, characterized in that a tube body (96) that contains the transmission unit and that extends in longitudinal direction of the tube is provided in the beam path within the tube in the tube (95) between the arrangement (73, 86) for intercepting and neutralizing the laser radiation and that end of the tube that faces toward the processing surface (81), said tube body (96) being centrally held within the tube, whereby
the transmission unit comprises a dispersing lens (101) that is arranged at that end of the tube body pointing to the housing (96) and picks up the laser radiation intended to produce a processing effect and widens it, whereby
the transmission unit comprises a positive lens (102) that shapes the widened laser radiation into approximately parallel ray bundles, and whereby an objective (103) onto which the laser radiation that is intended to produce a

processing effect is directed is provided at that end of the tube body (96) facing toward the processing surface (81), whereby the objective generates a processing spot (24) on the processing surface (81), and whereby
the unwanted laser radiation that should not produce a processing effect is redirected with a mirror (97) into the arrangement (73, 86) for intercepting and neutralizing the laser radiation.

132. Laser radiation source according to one of the claims 126 through 129, characterized in that
a first tube body (53) with two positive lenses (55, 56) is provided at that end of the tube (51) that is flanged to the housing (35, 93), said first tube body (53) being secured centrally relative to the beam axis to that end of the tube (51) facing toward the housing and within the tube at the ends thereof, an intermediate image (183) being generated therewith within the tube (51);
in that a second tube body (54) with two positive lenses (57, 61) is provided at the other end of the tube (51) that faces toward the processing surface (81), said second tube body (54) being secured centrally relative to the beam axis to that end of the tube (51) facing toward the processing surface (81) and within the tube at the ends thereof, a processing spot (24) on the processing surface (81) being generated therewith; and
in that the laser radiation that should not produce a processing effect is redirected with a mirror (74) that is arranged between the first tube body (53) and the second tube body (54), being redirected into the arrangement (73, 86) for intercepting and neutralizing the unwanted laser radiation that should produce no processing effect on the processing surface (81).

133. Laser radiation source according to one of the claims 130 through 132, characterized in that the arrangement for intercepting and neutralizing the unwanted laser radiation that should not produce a processing effect on the processing surface (81) contains an optical component (75) between the deflection mirror (74, 97, 121) or the polarization-dependent mirror (169) and the sump for collecting the unwanted laser radiation, said optical component

(75) separating the interior of the tube (51, 95, 113) from the sump and the diameter thereof being dimensioned such that the laser radiation conducted into the sump can just pass, whereas radiation that is reflected or scattered back from the sump is largely retained in the sump.

134. Laser radiation source according to claim 133, characterized in that the optical component (75) is a glass plate of a lens.

135. Laser radiation source according to claim 134, characterized in that the optical component (175) is anti-reflection coated.

136. Laser radiation source according to one of the claims 133 through 135, characterized in that the optical component (75) is glued or soldered into its mount.

137. Laser radiation source according to one of the claims 130 through 132, characterized in that the arrangement (73, 86) for intercepting the unwanted laser radiation is composed of a cylindrically fashioned intercept arrangement (73) with the deflection mirror (74, 97, 121), – or with the polarization-dependent mirror (169), – with the optical element (75) and a flange for fastening to the tube (51, 95, 113).

138. Laser radiation source according to one of the claims 110 through 112 or 127 or 130 through 132, characterized in that the sump for collecting the unwanted radiation is composed of a plate 86 that contains openings 87 through which a coolant can be conducted.

139. Laser radiation source according to claim 138, characterized in that the plate (86) has a planar surface at that side facing toward the laser radiation, said planar surface being inclined relative to the incident laser radiation.

140. Laser radiation source according to claim 139, characterized in that the surface of the plate is shaped crowned or hollow.

141. Laser radiation source according to claims 139 or 140, characterized in that the surface is roughened.

142. Laser radiation source according to claim 128 or 130 through 132, characterized in that

the arrangement for the removal of the material (82, 235, 249) eroded from the processing surface (81) comprises a through opening (207) for the laser radiation that passes through both end faces, whereby the end face at which the laser radiation emerges we [sic] brought close to the processing surface (81); and in that at least one further, laterally attached opening (213) that meets the through opening (207) and that is connected to a vacuum pump is located laterally at the arrangement close to the end face at which the laser radiation emerges.

143. Laser radiation source according to claim 142, characterized in that the through opening (207) is conically shaped between beam entry and beam exit and initially narrows toward the beam exit, but then merges into a widened processing space (211) immediately before the beam exit in the region of the laser radiation, the laterally attached opening being connected to said space (211) as extraction channel (213).

144. Laser radiation source according to claim 143, characterized in that a plurality of laterally attached extraction channels (213) are provided that are connected to a vacuum pump.

145. Laser radiation source according to one of the claims 143 or 144, characterized in that a bore (215) is provided in the processing space (211), said bore being connected to a compressed air supply and the axis thereof being directed onto the processing spot (24).

146. Laser radiation source according to claim 145, characterized in that the bore (215) is fashioned as nozzle bore whose acting direction is directed onto the processing spot (24).

147. Laser radiation source according to claim 146, characterized in that a plurality of nozzle bores (215) are provided.

148. Laser radiation source according to claims 143 through 147, characterized in that the nozzle bores (215) are attached to that side of the arrangement that lies opposite the side with the extraction channels.

149. Laser radiation source according to claims 143 through 148, characterized in that the nozzle bores (215) are attached to that side of the arrangement that lies opposite the side with the extraction channels and are offset relative to the extraction channels.

150. Laser radiation source according to one of the claims 143 through 149, characterized in that a further bore is provided as bypass bore (216) that is connected to the compressed air supply and that is arranged such that a flow derives along the opening 207 in the direction of the processing surface (81).

151. Laser radiation source according to claim 150, characterized in that a plurality of bypass bores (216) are provided that are connected to the compressed air supply and that are arranged such that a flow derives along the opening 207 in the direction of the processing surface (81).

152. Laser radiation source according to one of the claims 150 or 151, characterized in that at least one of the bypass bores (216) that are connected to the compressed air system is arranged such that a flow arises from the processing surface (81) in the direction of the beam entry, this being deflected by the objective lens (61, 103, 112) or by the glass plate (218, 230, 237) and moving along the opening 207 in the direction of the processing surface (81).

153. Laser radiation source according to one of the claims 150 through 152, characterized in that the bypass bores (216) have a smaller diameter than the nozzle bores (215).

154. Laser radiation source according to one of the claims 150 through 153, characterized in that the bypass bores (216) are present in greater numbers than the nozzle bores (215).

155. Laser radiation source according to one of the claims 146 through 154, characterized in that the nozzle bores (215) are present in greater numbers than the extraction channels (213).

156. Laser radiation source according to one of the claims 145 through 155, characterized in that the extraction channels (213) have a larger crossection than the nozzle bores (215).

157. Laser radiation source according to one of the claims 142 through 156, characterized in that an extraction channel (212) with a cover (217) for the acceptance of the extraction connectors (221) for the connection of the vacuum pump is provided.

158. Laser radiation source according to one of the claims 142 through 157, characterized in that a filter device that picks up material released in the processing is arranged between the extraction channels (213) and the vacuum pump.

159. Laser radiation source according to claim 158, characterized in that the filter device is arranged in the extraction channel.

160. Laser radiation source according to one of the claims 142 through 159, characterized in that an intake air channel (214) with a cover for the acceptance of the intake air connectors (222) for the connection of the compressed air supply is provided via which the nozzle bores (215) and the bypass bores (216) are supplied.

161. Laser radiation source according to one of the claims 142 through 160, characterized in that an oxidation-promoting gas is employed instead of compressed air.

162. Laser radiation source according to one of the claims 142 through 160, characterized in that an oxidation-inhibiting gas is employed instead of compressed air.

163. Laser radiation source according to one of the claims 142 through 162, characterized in that the arrangement for the removal of the material eroded from the processing surface (81)
is fashioned as cylindrical mouthpiece (82) that is releasably secured with devices (204) to that end of the tube (51, 95, 113) from which the laser radiation emerges; and
in that a cylindrical widening (206) of the opening (207) is present at the end of the beam entry into the mouthpiece, the mount of the objective lens (61, 103, 112) projecting thereinto.

164. Laser radiation source according to claim 163, characterized in that the cylindrical mouthpiece (82) is composed of a cylindrical base member (205) that comprises the opening (207) that is implemented as conical bore, that further contains the processing space (211), the extraction channels (213), the extraction channel (212), the nozzle bores (215), the bypass bores (216), the intake air channel (214) and the cylindrical bore (206), whereby a ring (217) that contains one or more extraction connectors for the connections to the vacuum pump and at least one intake air connector for the connection to the compressed air supply is put in place gas-tight on the base member.

165. Laser radiation source according to claim 164, characterized in that an interchangeable glass plate (218) is provided in the cylindrical widening (206) of the opening (207).

166. Laser radiation source according to one of the claims 10 through 104 or 119 through 132, characterized in that the optical unit (8) for shaping the laser beam is implemented such that beam narrowings derive on the processing surface (81).

167. Laser radiation source according to one of the claims 10 through 104 or 119 through 132 or 166, characterized in that the optical unit (8) comprises a displaceable lens with a long focal length, whereby the focussing of the processing spots on the processing surface can be varied as a result of the displacement.

168. Laser radiation source according to one of the claims 1o through 104 or 119 through 132 or 166, characterized in that the optical unit (8) comprises a vario-focussing optics with which, on the basis of a first adjustment, the spacing between the processing points on the processing surface (81) is variable in a predetermined range, and with which. on the basis of a second adjustment, the focussing of the processing spots on the processing surface can be set.

169. Laser radiation source according to one of the claims 10 through 168, characterized in that the optically effective surfaces of the components are provided with reflection-reducing coatings.

170. Laser radiation source according to one of the claims 10 through 169, characterized in that the optically effective surfaces are arranged inclined relative to the laser radiation in order to prevent back-reflection and back-scatter into the lasers (Figure 3, Figure 18, Figure 38).

171. Laser radiation source according to one of the claims 19 through 170, characterized in that the acousto-optical modulators are arranged such with respect to the incident laser radiation that the radiation (I_0) that just passes through and is not deflected produces a processing effect and that the deflected radiation (I_1) does not produce a processing effect.

172. Laser radiation source according to one of the claims 19 through 171, characterized in that the acousto-optical modulators (34) are arranged such with respect to the incident laser radiation that the deflected radiation (I_1) produces a processing effect and that the radiation (I_0) that just passes through and is not deflected does not produce a processing effect.

173. Laser radiation source according to one of the claims 10 through 172, characterized in that means that prevent a contamination of the optical surfaces are provided at the optical unit (8) for shaping the laser beam.

174. Laser radiation source according to one of the claims 10 through 173, characterized in that the means for preventing the contamination of the optical surfaces are comprised therein that the receptacle and/or the optical unit (8) are free of materials that give off gasses, can be closed gas-tight, and therein that optical windows are provided for the exit of the laser radiation.

175. Laser radiation source according to one of the claims 10 through 174, characterized in that the optical windows through which the laser radiation exits are glass plates.

176. Laser radiation source according to one of the claims 10 through 175, characterized in that the optical windows through which the laser radiation emerges are glass plates or lenses.

177. Laser radiation source according to one of the claims 120 through 176, characterized in that the parts of the receptacle for the adaptation of the optical unit (8) (35, 93, 51, 95, 113) are connected to one another gas-tight; and in that the assemblies (26, 94, 37, 41, 46, 73, 54, 96, 116, 118) connected to it are attached gas-tight.

178. Laser radiation source according to one of the claims 120 through 177, characterized in that seals (36, 43, 52, 76, 62, 124, 125) are provided as means for sealing.

179. Laser radiation source according to one of the claims 120 through 178, characterized in that gluings are provided as means for sealing.

180. Laser radiation source according to one of the claims 120 through 178, characterized in that solderings are provided as means for sealing.

181. Laser radiation source according to one of the claims 120 through 180, characterized in that the objective lens (61, 103, 112) is provided as optical window for the passage of the laser radiation that is intended to produce a processing effect.

182. Laser radiation source according to one of the claims 120 through 181, characterized in that the plate (117) is provided as optical window for the passage of the laser radiation that is intended to produce a processing effect.

183. Laser radiation source according to one of the claims 120 through 182, characterized in that the lens (75) is provided as optical window for the passage of the laser radiation that is not intended to produce a processing effect.

184. Laser radiation source according to one of the claims 120 through 183, characterized in that a valve (77) via which the interior of the receptacle for the adaptation of the optical unit (8) can be evacuated is provided at the housing.

185. Laser radiation source according to one of the claims 120 through 184, characterized in that a filling of the interior of the receptacle for the adaptation of the optical unit (8) with a protective atmosphere is provided via the valve (77).

186. Laser radiation source according to one of the claims 120 through 185, characterized in that a flow-through of the interior of the receptacle for the adaptation of the optical unit (8) with a protective atmosphere via the valve (77) is provided during an opening of one of the provided seals.

187. Laser radiation source according to one of the claims 120 through 186, characterized in that a constant flow-through of the interior of the receptacle for the adaptation of the optical unit (8) with a protective atmosphere via the valve (77) is provided, whereby at least one opening 120 Figure (39a) is provided in the proximity of the objective lens (61, 103, 112) for the escape of the protective atmosphere.

188. Laser radiation source according to one of the claims 120 through 187, characterized in that the protective atmosphere is composed mainly of nitrogen.

189. Laser radiation source according to one of the claims 120 through 188, characterized in that the receptacle for the adaptation of the optical unit (8) to the housing (35, 93) is provided with cooling ribs is the region of the terminators (26, 94).

190. Laser radiation source according to one of the claims 120 through 189, characterized in that the receptacle for the adaptation of the optical unit (8) to the housing (35, 93) is provided with bores 87 for the delivery of a coolant in the region of the terminators (26, 94).

191. Laser radiation source according to one of the claims 120 through 190, characterized in that the receptacle for the adaptation of the optical unit (8) to the tube (118) is provided with cooling ribs in the region of the intercept unit (73) and the objective lens 112.

192. Laser radiation source according to one of the claims 120 through 191, characterized in that the optical unit (8) is provided with bores (87) for the delivery of a coolant in the region of the terminators and/or lenses (Figure 8, Figure 39).

193. Laser radiation source according to one of the claims 120 through 192, characterized in that the modulator housing (172) is provided with bores (87) for the delivery of a coolant in the region of the modulator (34).

194. Laser radiation source according to one of the claims 1 through 193, characterized in that the structure is partly modularly implemented in that modules are provided that are respectively composed of a fiber laser (2) with the pump source (18), the laser fiber (5) and the terminator (26, 94).

195. Laser radiation source according to one of the claims 1 through 194, characterized in that the modules comprise a passive fiber (28) between the laser fiber (5) and the terminator (26, 94).

196. Laser radiation source according to one of the claims 1 through 195, characterized in that at least one module comprises a plurality of laser outputs (13) with passive fibers (28) that are respectively provided with a terminator (26, 94).

197. Laser radiation source according to one of the claims 1 through 196, characterized in that at least one laser output is provided that is provided with a terminator ( ) [sic] and to which a plurality of fiber laser modules are connected.

198. Laser radiation source according to claim 194, characterized in that an electronics module for the drive of the fiber laser module is provided for each module that contains a fiber laser.

199. Laser radiation source according to claim 198, characterized in that the electronics modules are connected to one another via a shared bus.

200. Laser radiation source according to one of the claims 1 through 199, characterized in that a slight part of the pump radiation can be coupled out of the laser fiber (5) for a measuring cell.

201. Laser radiation source according to claim 200, characterized in that a control circuit is provided for comparing the pump radiation to a rated value, whereby a deviation acts on the power supply such that the deviation is eliminated.

202. Laser radiation source according to one of the claims 10 through 201, characterized in that the optical unit (8) for shaping the laser beam comprises a beam splitter at its radiation input for taking and measuring a slight part of the laser radiation.

203. Laser radiation source according to one of the claims 10 through 202, characterized in that a control circuit is provided for comparing the radiation of every ray bundle (144) at the radiation entry (90 of the optical unit (8) to a rated value, whereby a deviation acts on the power supply of the pump source such that the deviation is eliminated.

204. Laser radiation source according to one of the claims 19 through 203, characterized in that the optical unit (8) comprises a beam splitter in the beam path following the modulator for taking and measuring a slight part of the laser radiation.

205. Laser radiation source according to one of the claims 19 through 204, characterized in that a control circuit is provided for comparing the radiation following the modulator to a rated value, whereby a deviation acts on the electrical drive of the modulator such that the deviation is eliminated.

206. Laser radiation source according to one of the claims 1 through 205, characterized in that continuous wave (CW) lasers are provided that can be modulated with a modulator arranged outside the laser resonator.

207. Laser radiation source according to one of the claims 1 through 205, characterized in that quality switched (Q-switch) lasers are provided that can be modulated with a modulator arranged outside the laser resonator.

208. Laser radiation source according to one of the claims 1 through 205, characterized in that continuous wave (CW) lasers are provided that can be modulated by means of the pump energy.

209. Laser radiation source according to one of the claims 1 through 205, characterized in that quality switched (Q-switch) lasers are provided that can be modulated by means of the pump energy.

210. Laser radiation source according to one of the claims 1 through 205, characterized in that quality switched (Q-switch) lasers are provided that can be modulated by means of the Q-switch.

211. Laser radiation source according to one of the claims 1 through 210, characterized in that the lasers can be directly modulated via separate modulation inputs.

212. Arrangement for processing material with lasers according to one of the claims 1 through 211, characterized by
a housing (21) for the acceptance of individual components of the arrangement,
at least one rotatably seated drum (22) arranged in the housing that is placed into rotation by a drive and on whose surface a processing surface (81) is provided,
a laser radiation source (1) that is composed of a plurality of fiber lasers (2) and contains a laser gun (23) whose radiation is directed onto the processing surface (81),
at least one carriage arranged in the housing that a feed drive can axially displace on a guide along the drum and on which the laser gun (23) is arranged,
a cooling system,
a control for the lasers, and
a machine control for the drives.

213. Arrangement for processing material according to claim 212, characterized in that a plurality of laser radiation sources (1) are provided at each drum.

214. Arrangement for processing material according to one of the claims 212 or 213, characterized in that an arrangement (82) for removal of the material eroded from the processing surface is provided for each laser radiation source.

215. Arrangement for processing material with lasers according to one of the claims 1 through 211,906, characterized by
a housing for the acceptance of individual components of the arrangement,
at least one rotating mirror (243) having at rotational drive with which the lasers can be deflected line-by-line,
an optical means (242, 245) for focussing the lasers,
a table (247) having a processing surface (81) that is arranged on a linear guide (251) for generating a relative linear motion between the table and the laser radiation source and can be axially displaced with a drive (252), 253, 254),
a laser radiation source (1) that is composed of a plurality of fiber lasers (2),
a cooling system,
a control for the lasers, and
a machine control for the drives.

216. Arrangement for processing material according to claim 215, characterized in that a plurality of laser radiation sources (1) are provided.

217. Arrangement for processing material according to one of the claims 2156 or 216, characterized in that an arrangement (249) for the removal of the material eroded from the processing surface is provided for each laser radiation source.

218. Arrangement for processing material with lasers according to one of the claims 1 through 211, characterized by
a housing for the acceptance of individual components of the arrangement,
at least one rotating mirror (243) with a rotational drive with which the lasers can be deflected line-by-line,
a hollow bed (236) with a processing surface (81), whereby a linear guide with a drive is provided for generating a relative linear motion between the hollow bed and the laser radiation source,
an optical means (231, 232) for focussing the lasers onto the processing surface,
a laser radiation source (1) that is composed of a plurality of fiber lasers (2),
a cooling system,

a control for the lasers, and
a machine control for the drives.

219. Arrangement for processing material according to claim 218, characterized in that a plurality of laser radiation sources (1) are provided.

220. Arrangement for processing material with lasers according to one of the claims 218 or 219, characterized in that an arrangement (235) for the removal of the material eroded from the processing surface is provided for each laser radiation source.

221. Arrangement for processing material with lasers according to one of the claims 1 through 211, characterized by
a housing for the acceptance of components of the arrangement,
a table (225) for the acceptance of the material to be processed,
at least two fiber lasers (2) for generating of plurality of processing tracks that are arranged on a profiled rail (256) and are provided with terminators (26, 94) with which the lasers can be aligned and focussed onto the processing surface (81), whereby the terminators are arranged such on the profiled rail that the mutual spacing of the processing tracks (224) generated by the terminators is variable,
actuating drives with which the table is movable relative to the profiled rail along at least one of the spatial coordinates x, y, z and/or is rotatable by an angle φ around a rotational axis z proceeding approximately perpendicularly through the processing surface and/or actuating drives with which the profiled rail is movable relative to the table along at least one of the spatial coordinates x, y, z,
a cooling system,
a control for the lasers, and
a machine control for the drives for generating the relative motions and the rotational movements.

222. Arrangement for processing material according to claim 221, characterized in that an arrangement for the removal of the material (249) eroded from the processing surface is provided for each processing track.

223. Arrangement for processing material according to claim 221, characterized in that a shared arrangement for the removal of the material (249) eroded from the processing surface is provided.

224. Arrangement for processing material according to claims 212 through 223, characterized in that the profiled rail is arranged rotatable around an axis z' for varying the spacing between the processing tracks.

225. Arrangement for processing material according to claims 212 through 224, characterized in that means are provided for the compensation of the distortions in the recorded patterns arising due to the rotation, said means being composed of a pre-distortion of the pattern to be applied and/or influencing the time control of the data stream.

226. Arrangement for processing material according to claims 212 through 220, characterized in that acousto-optical deflectors or modulators are provided that comprise control inputs for varying the spacing between the processing tracks and/or the laser power during the processing event.

227. Arrangement for processing material according to claims 212 through 220, characterized in that means are provided for measuring the deviation of the position of the processing tracks from their rated position during the processing event, whereby control signals are generated due to the deviations, said control signals acting such on the acousto-optical deflection of the laser beams during the processing event that the deviations are eliminated.

228. Arrangement for processing material according to claims 1 through 27 or 212 or 221 (Figure 3, Figure 42), characterized in that the outputs of the laser radiation source (Figure 40) slide directly on the surface of the material.

229. Arrangement for processing material according to one of the claims 212 through 220, characterized in that a laser radiation source (1) that is

composed of a plurality of fiber lasers (2) is provided with which depressions or, respectively, cups can be engraved in the processing surface (81).

230. Arrangement for processing material according to claim 229, characterized in that a scraper and/or brush device is provided for scraping off and/or brushing off the material erosion arising during the processing of the material.

231. Arrangement for processing material according to one of the claims claim [sic] 212 through 230, characterized in that a measuring device is provided for determining the volumes of the depression or, respectively, cups that are cut out; and in that a control circuit is provided for comparing the measured cup volumes to a rated value, whereby control signals are generated due to the deviations that act such on the lasers that the deviations are eliminated.

232. Arrangement for processing material according to claims 212 through 231, characterized in that the volumes of the cups can be varied proportional to the area, these arising in the surface of the processing surface in that material is removed from the surface due to the engraving of the cups.

233. Arrangement for processing material according to claim 232, characterized in that the volumes of the cups are respectively [...] via their areas and via their depths, which are variable by varying the laser power via a control of the amplitudes of the control voltages at the control inputs of the modulators.

234. Arrangement for processing material according to claim 232, characterized in that the volumes of the cups are variable via the depths of the cups given a respectively constant area.

235. Arrangement for processing material according to claims 233 or 234, characterized in that the depth of the cups is digitally variable in at least two steps.

236. Arrangement for processing material according to claim 233 or 234, characterized in that the depth of the cups is infinitely variable.

237. Operating mode of an arrangement for processing material according to claims 212 through 236, characterized in that the cups are designed such in shape and are arranged such in their position on the processing surface (81) that printing screens known in printing technology having variable screen angles and variable screen sizes (regular screens) are generated on the processing surface.

238. Operating mode of an arrangement for processing material according to claims 212 through 237, characterized in that the cups are designed such in shape and are arranged such in their position on the processing surface (81) that stochastic screens known in printing technology or combinations of stochastic screens with regular screens are generated.

239. Operating mode of an arrangement for processing material according to claim 238, characterized in that screens for offset printing, rotogravure printing, letterpress printing, silkscreening, flexo printing and transfer printing are produced.

240. Arrangement for processing material with lasers according to one of the claims 1 through 211, characterized by
a housing for the acceptance of individual components of the arrangement,
at least one oscillating mirror with which the lasers can be deflected,
an optical device (242, 245) for focusing the lasers,
a laser radiation source (1) that is composed of a plurality of fiber lasers (2),
a table (247) having a processing surface (81) that is arranged on a linear guide (251) for generating a relative linear motion between the table and the laser radiation source and can be axially displaced with a drive (252), 253, 254), or a cassette in which the material to be processed is guided,
a cooling system,
a control for the lasers, and
a machine control for the drives.

241. Arrangement for processing material according to claim 240, characterized in that a plurality of laser radiation sources (1) are provided.

242. Arrangement for processing material according to claim 240 or 241, characterized in that an arrangement (249) for the removal of the material eroded from the processing surface is provided for each laser radiation source (1).

243. Operating mode of an arrangement for processing material according to one of the claims 212 through 242, characterized in that patterns for the contacting of photovoltaic cells are generated.

244. Operating mode for an arrangement for processing material according to claim 243, characterized in that

the patterns for the contacting of photovoltaic cells are applied such that, without varying the spacing of the processing, the contact tracks, which lie far apart compared to the track width, are applied in one step; and in that

the tracks for the busbars, which lie close to one another compared to the track width, are applied in a further step.

245. Operating mode of an acousto-optical modulator for processing material, characterized in that the laser radiation that just passes through produces a processing effect; and in that, for modulating this radiation according to a modulation signal, the power of a plurality of different frequencies is applied to the acousto-optical modulator in order to bend off a part of the radiation just passing through in conformity with the modulation signal and to direct sub-beams appertaining in the frequencies onto the processing surface, whereby the power density of the sub-beams is so low that they produces [sic] no processing effect.

246. Operating mode of an acousto-optical modulator for processing material according to claim 245, characterized in that the various frequencies are matched such to the divergence of the ray bundle just passing through that an especially large part of the radiation of the ray bundle just passing through is bent off in conformity with the modulation signal.

247. Arrangement for processing material with lasers according to one of the claims 1 through 211, characterized by

a housing for the acceptance of individual components of the arrangement, at least one deflection unit with a deflection mirror, an objective connected to the deflection mirror for focussing the lasers and a linear drive with which the lasers can be deflected line-by-line,

a laser radiation source (1) that is composed of a plurality of fiber lasers (2),

a table (247) having a processing surface (81) that is arranged on a linear guide (251) for generating a relative linear motion between the table (247) and the laser radiation source and that is axially displaceable with a drive,

a cooling system,

a control for the lasers, and

a machine control for the drives.

248 Arrangement for processing material according to claim 247, characterized in that a plurality of laser radiation sources (1) are present.

249. Arrangement for processing material according to one of the claims 247 or 248, characterized in that a plurality of laser radiation sources (1) and a plurality of deflection units with which the lasers can be deflected line-by-line are present.

250. Arrangement for processing material according to one of the claims 247 through 249, characterized in that an arrangement (249) for the removal of the material eroded from the processing surface (81) is provided for each deflection unit.

251. Arrangement for processing material according to one of the claims 247 through 250, characterized in that the drive of the deflection unit ensues by means of a thrust [sic] into the corresponding direction.

252. Arrangement for processing material according to claim 251, characterized in that the thrust ensues non-contacting.

253. Arrangement for processing material according to claim 251 or 252, characterized in that the thrust is electromagnetically triggered.

254. Arrangement for processing material according to one of the claims 247 through 253, characterized in that the guide rail is a matter of a low-friction bearing (air bearing, magnetic bearing).

255. Arrangement for processing material according to one of the claims 247 through 254, characterized in that the energy acquired from the deceleration of the moving deflection unit is partially employed for the drive.

256. Arrangement for processing material according to one of the claims 247 through 255, characterized in that the respective, true position of the moving unit is determined via a reference unit.

257. Arrangement for processing material according to one of the claims 247 through 256, characterized in that a reference signal is utilized for the control of the data stream.

258. Arrangement for processing material according to one of the claims 247 through 257, characterized in that one or both drives for the deflection unit are displaceably arranged on the linear guide.

259. Arrangement for processing material according to claim 215 through 258, characterized in that at least one laser radiation source (1) is provided for each processing surface (81) and at least one further laser is provided.

260. Arrangement for processing material according to claim 259, characterized in that the laser radiation source (1) is used mainly for processing finer contours, and the further laser is used mainly for processing rougher contours.

261. Arrangement for processing material according to one of the claims 259 or 260, characterized in that an arrangement (82) for the removal of the material eroded from the processing surface (81) is provided for each of the further lasers.

262. Laser radiation source according to one of the claims 31, 32, 53 through 58, 122, characterized in that the terminators are adjustable within the mounts.

263. Laser radiation source according to one of the claims 1 through 262, characterized in that a processing spot (24) that is at rest relative to the processing surface (81) arises as a result of entraining the processing spot (24) in the direction of the motion of the processing surface (81) during the processing event.

Abstract

The invention is directed to a laser radiation source, preferably for processing material, as well as to an arrangement for processing material with the laser radiation source and to the operation thereof. For achieving a high power density and energy, the laser radiation source (1) comprises a plurality of directly modulatable diode-pumped fiber lasers (2) whose outputs are arranged in a bundle. The laser radiation emerging from the outputs of the fiber lasers (2) is merged and bundled such with an optical unit that the laser radiation is incident onto a processing surface (81) in a processing spot (24).

Figure 1

39/PRTS

09/786742

JC02 Rec'd PCT/PTO 0 8 MAR 2001

SPECIFICATION

TITLE

LASER RADIATION SOURCE

BACKGROUND OF THE INVENTION

The invention is directed to a laser radiation source, preferably for processing materials, as well as to an arrangement for processing material comprising a laser radiation source and to the operation thereof.

When processing materials with focused energy beams such as, for example, electron beams or laser beams, there are applications wherein structures must be produced that make high demands of the focused energy beam with respect of its beam geometry and the focusability of the beam. At the same time, however, a high steel power is required.

A typical case wherein extremely fine structures must be produced on a processing surface is the production of printing forms, whether for rotogravure, offset printing, letter press printing, silk screening or flexo-printing or for other printing processes. In the production of printing forms, it is necessary to produce extremely fine structures on the surface of the printing forms, since highly resolved image information such as text, screened images, graphics and line work must be reproduced with the surface of the printing forms.

In rotogravure, the printing forms were produced in the past with etching, which had led to good results; the etching, however, was replaced over the course of time by more environmentally friendly engraving with electromagnetically driven diamond stylii. Printing cylinders whose surface is composed of copper are normally employed as printing forms in rotogravure, these fine structures required for the printing being engraved thereinto in the form of cups with the diamond stylus. The printing cylinders are introduced into a printing press after they are produced, the cups being filled with ink therein. Subsequently, the excess ink is removed with a doctor blade and the remaining ink is transferred

onto the printed matter during the printing process. Copper cylinders are thereby employed because of their long service life in the printing process. A long service life is required given large editions, for example, in particular, in magazine printing or packaging printing, since the surface of the printing form wears in the printing process as a result of the influence of the doctor blade and of the printed matter. In order to extend the service life even further, the printing cylinders are provided with a copper layer that has been galvanized on; on the other hand, solid cylinders of copper are employed. Another possibility of making the service life even longer is comprised in galvanically chrome plating the copper surface after the engraving. In order to achieve an even longer surface life, what is referred to as "hot chrome plating" is additionally applied, whereby the galvanic process is carried out under elevated temperature. The longest service lives that could previously be obtained were achieved therewith. Deriving therefrom is that copper is the most suitable as the material for the surface of rotogravure cylinders. Materials other than copper have not hitherto proven themselves for large editions.

When producing the cups, the drive of the diamond stylus occurs via an electromechanically driven magnet system having an oscillating armature to which the diamond stylus is secured. Such an electromechanical oscillatory system cannot be made arbitrarily fast because of the forces that must be exerted in order to engrave the cups. This magnet system is therefore operated above its resonant frequency so that the highest engraving frequency, i.e. the highest engraving speed can be achieved. In order to increase the engraving speed even further, a number of such engraving systems have been arranged side-by-side in the axial direction of the copper cylinder given current engraving machines. This, however, still does not suffice for the short engraving time of the printing cylinders required currently, since the engraving time directly influences the current nature of the printing result. For this reason, rotogravure is not employed for newspaper printing but mainly for magazine printing.

Upon utilization of a plurality of engraving systems, a plurality of what are referred to as lanes are simultaneously engraved into the surface of the printing cylinder. For example, such a lane contains one or more entire magazine pages. One problem that thereby arises is that cups having different volumes are generated in the individual lanes given the same tone value to be engraved, this occurring because of the different engraving systems that are driven independently of one another and leading to differences in the individual lanes that the eye detects during later observation. For this reason, for example in packaging printing, only one engraving system is employed so that these errors, which are tolerated in magazine printing, do not occur.

When engraving the cups, the cup volume is varied dependent on the image content of the master to be printed. The respective tone value of the master should thereby be reproduced exactly as possible during printing. When scanning the masters, the analog-to-digital converters having, for example, a resolution of 12 bits are utilized for recognizing the tone value gradations for reasons of image signal processing (for example, gradation settings), this corresponding to a resolution of 4096 tone values in this case. The signal for the drive of the electromagnetic engraving system is acquired from this high-resolution image information, said signal usually being an 8-bit signal corresponding to a resolution into 256 tone value gradations. In order to generate the corresponding volumes that are required for achieving this scope of gradations, the penetration depth of the diamond stylus into the copper surface is varied with the drive of the magnet system, whereby the geometry of the cups changes between approximately 120 μm diameter given a depth of 40 μm and approximately 30 μm diameter given a depth of 3 μm. Because only an extremely small range of variation in the depth of the cups between 40 μm and 3μm is available, the penetration depth of the stylus with which the cups are engraved must be exactly driven to fractions of a μm in order to reproducibly achieve the desired range of gradation. As can be seen therefrom, an extremely high precision is required in the engraving of the cups, at least as regard to the generation of the required diameters and depths of the cups.

Since the geometry of the engraved cups is directly dependent on the shape of the stylus, extremely high demands are also made of the geometry of the diamond stylus which, as has been shown, can only be achieved with extremely high expense and with a high rejection rate in the manufacture of the stylii. Moreover, the diamond stylus is subject to wear since, when engraving a large printing cylinder having fourteen lanes, a circumference of 1.8m and a length of 3.6m given a screen of 70 lines/cm - which corresponds to a plurality of 4900 cups/cm^2, a stylus must engrave approximately 20 million cups. When one of the diamond stylii breaks off during the engraving of a printing cylinder, then the entire printing cylinder is unuseable. On the one hand, this causes a considerable financial loss and, on the other hand, represents a serious loss of time since a new cylinder must be engraved, postponing the start of printing by hours. For this reason, users frequently replace stylii earlier than necessary. As can also be seen therefrom, the endurance of the diamond stylii is also a critical concern.

All in all, electromagnetic engraving is well-suited for producing high-quality rotogravure cylinders; however, it has a number of weak points and is extremely complicated and one would like to eliminate these disadvantages with a different method.

The cups produced in this way, which are intended to accept the ink later, are also arranged on the surface of the printing form in conformity with a fine, regular screen, namely the printing screen, whereby a separate printing cylinder is produced for each ink, and whereby a different screen having a different angle and different screen width is respectively employed. When printing in the printing press, given these screens, narrow webs remain between the individual cups, these supporting the doctor blade that removes the excess ink after the inking. Another disadvantage of this operating mode of this electromechanical engraving is that texts and lines must also be reproduced in screened fashion, which leads to step-patterns in the contours of the written characters and the lines that the eye perceives as being disturbing. This is one advantage compared to the widespread offset printing wherein this stepping can be kept an order of magnitude lower,

which can then no longer be perceived by the eye, and which leads to a better quality that rotogravure could hitherto not achieve. This is a serious disadvantage of the rotogravure process.

In rotogravure, no stochastic screens can be generated wherein the size of the cups and the position of the cups can be randomly distributed corresponding to the tone value; this is not possible when engraving with the diamond stylus. Such stochastic screens are also frequently referred to as "frequency-modulated screens" that have the advantage that details can be reproduced far better with no Moirè, this also leading to a better image quality than in rotogravure.

It is also known to utilize the electron beam engraving method applied in the processing of materials for generating the cups, this having exhibited extremely good results because of the high energy of the electron beam and the incredible precision with respect to the beam deflection and beam geometry.

This method is described in the publication, "Schnelles Elektronenstrahlgravierverfahren zur Grvur von Metallzylindern", Optik 77, No. 2 (1987) pages 83-92, Wissenschaftliche Verlagsgesellschaft mbH Stuttgart. Due to the extremely high expense that is required for the hardware and electronics, electron beam engraving has hitherto not prevailed in practice for the engraving of copper cylinders for rotogravure but only in the steel industry for surface engraving of what are referred to as textured drums for sheet metal manufacture wherein textures are rolled into the sheets.

It has been repeatedly proposed in the trade literature as well as in the patent literature to engrave copper cylinders with lasers. Since copper, however, is an extremely good reflector for laser radiation, extremely high powers and, in particular, extremely high power densities of the lasers to be employed are required in order to penetrate into the copper and melted. There has hitherto not been any laser engraving unit with laser radiation sources having a correspondingly high powered density and energy with which one succeeds in providing the copper cylinders for rotogravure with the required cup structure in the copper surface.

Attempts have nonetheless been made to utilize lasers for rotogravure in that a switch has been made to materials other than copper. Thus, for example, the publication DE-A-19 20 323 has proposed to prepare copper cylinders with chemical etching such that the surface of the copper cylinder already comprises cups that have a volume that corresponds to the maximum printing density. These cups are filled with a solid filler material, for example plastic. Much of the filler material is then removed with a laser until the desired cup volume has been achieved. This method in fact manages with a lower laser power than would be necessary in order to melt and evaporate the copper as in electron beam engraving. In this method, however, the remaining plastic is attacked by the solvent of the ink in the printing process and is decomposed, so that only a low print run is possible. This method has not proven itself in practice and has thus not been utilized.

The publication of the VDD Seminar Series, "Direktes Lasergravierverfahren für metallbeschichtete Tiefdruckzylinder", published within the framework of a "Kolloquium vom Verein Deutscher Druckingenieure e.V. und dem fachgebiet Druckmaschinen und Druckverfahren, Fachbereich Maschinenbau, technische Hochschule Darmstadt", by Dr. phil. Nat. Jakob Frauchiger, MDC Max Dätwyler, AG, Darmstadt, 12 December 1996, has proposed that rotogravure cylinders plated with zinc be engraved by a quality-switched Nd:YAG high-power solid-state laser pumped with arc lamps. In this method, the volume of the cups is defined by the optical power of the laser. The laser power required for the engraving is transmitted onto the cylinder surface via an optical fiber whose output is imaged onto the cylinder surface through a variable focusing optics. One disadvantage of this method is that the arc lamps required for pumping the laser have a relatively short service life and must be replaced after approximately 500 hours of operation. The engraving cylinder becomes unuseable given a failure of the pump light source during the engraving. This corresponds to a failure of the diamond stylus in electromechanical engraving and results in the same disadvantages. A preventative replacement of

the arc lamps is cost-intensive and work-intensive, particularly since one must count on the fact that the laser beam must be re-adjusted in position after the replacement of the lamps. These lamp-pumped solid-state lasers also have a very poor efficiency since the laser-active material absorbs only a slight fraction of the available energy from the pump source, i.e. from the arc lamp here, and converts into laser light. Particularly given high laser powers, this means a high electrical connection cost, high operating costs for electrical energy and cooling and, in particular, a considerable expense for structural measures due to the size of the laser and the cooling unit. The space requirements are so high that the laser unit must be located outside the machine for space reasons, this in turn being accompanied by problems in bringing the laser output onto the surface of the printing cylinder.

A critical disadvantage of this method is that zinc is significantly softer than copper and is not suitable as a surface material for printing cylinders. Since the doctor blade with which the excess ink is removed before printing in the printing press is a steel blade, the zinc surface is damaged after a certain time and the printing cylinder becomes unuseable. A printing cylinder having a surface of zinc therefore does not even begin to approach as long a service life in printing as a printing cylinder having a surface of copper. Printing forms having a zinc surface are therefore not suitable for high press runs.

Even if the zinc surface is chrome-plated after the engraving, as has been also proposed in order to lengthen the service life, the durability does not come close to that of normal copper cylinders. Chrome does not adhere to zinc as well as it adheres to copper and what is referred to as "hot chrome plating", which is successfully employed given copper cylinders in order to achieve an optimum adhesion of the chromium on the copper, is not possible given zinc since the zinc would thereby melt. Since the chrome layer does not adhere very well on the zinc, it is likewise attacked by the doctor blade, which leads to a relatively early failure of the printing cylinders. When, in contrast thereto, copper cylinders are chrome-plated according to this method, then incredibly high press runs are

possible since the chromium firmly adheres on the copper surface, so that these copper cylinders out perform the chrome-plate zinc cylinders by far.

It proceeds from the publication EP-B-0 473 973, which is likewise directed to the method described above, that an energy of 6 mWsec is required in this method given zinc for cutting a cup having a diameter of 120 μm and a depth of 30 μm. An energy of 165 mWsec is recited in this publication for copper, this amounting to a factor of 27.5 for the required laser power. Lasers having a continuous-wave performance of several kilowatts given good beam quality are thus required in order to produce cups in copper with a speed that is accessible for the printing industry. Such a power, however, cannot be produced with the laser arrangement described above. For this reason, it is likewise only possible to engrave a zinc surface.

Such a laser arrangement, which is composed of a single solid-state laser, in fact makes it possible to process rotogravure cylinders having a zinc surface; if, however, one wishes to utilize the advantages of the copper surface and stay with copper cylinders and engrave these with a laser, the high power density required for penetration into the surface of the copper and the high energy required for melting the copper must be inevitably exerted. This, however, has not hitherto been successfully done with a solid-state laser.

It is known that the beam quality in solid-state lasers, i.e. the focusability, decreases with increasing power. Even if the power of the solid-state lasers were to be driven up or if a plurality of solid-state lasers were directed onto the same cup or parts thereof, it would therefore not be possible to satisfactorily engrave copper cylinders for rotogravure with such a laser because the precision of the laser beam, as offered by the electron beam, required for generating the fine structures cannot be achieved. If the laser power were increased given this apparatus, then a further problem would arise: the focusing of high radiant intensity in optical fibers is, as known, difficult. The fibers burn at high power as a consequence of misadjustment at the infeed location. If one wishes to avoid this, however, the fiber diameter would have to be enlarged which, however, in

turn has the disadvantage that the fiber diameter would have to be imaged onto the processing page with even greater demagnification. A demagnified imaging, however, leads to an increase in the numerical aperture on the processing page and, consequently, to a reduced depth of field on the processing surface. As proposed, the distance from the processing surface could be kept constant. When, however, the beam penetrates into the surface of the material, then a defocussing automatically derives. This has a disadvantageous influence on the required power density and on the exact dot size. Since, however, the diameter of the processing spot and the energy of the beam determine the size of the cup, it then becomes difficult to make the cup size exactly as required by the desired tone value. For this purpose, it would also be necessary that the laser power is exactly constant and also remains constant over the entire time that is required for a cylinder engraving. When this is not the case, the cup size changes and the cylinder becomes unuseable. This cannot be compensated by varying the size of the processing spot since it is not possible to adequately vary the processing spot in shape.

Further, a complicated modulator is required given such an arrangement. As known, modulators for extremely high laser powers are slow, this leading to a reduction of the modulation frequency and, thus, of the engraving frequency. When, however, the engraving frequency is too low, the energy diffuses into the environment of the processing spot on the processing surface without cutting out a cup. It is therefore necessary to also exert a high power in addition to the high energy for the cutting.

The publication "Der Laser in der Druckindustrie", by Werner Hülsbuch, page 540, Verlag W. Hülsbusch, Constanc, describes that it is particularly a matter of a high powered density in processing materials given power densities of typically above 10^7 through 10^8 W/cm^2, a spontaneous evaporation of the material occurs in all materials, this being accompanied by a sudden absorption rise, which is especially advantageous since the laser power is then no longer reflected from the metal surface. When, for example, a laser source of 100 W is available, then

the processing spot dare not be larger than 10 μm in order to arrive at these values in the region, as proceeds from the following equation: 100 W : (0.001 cm x 0.001 cm)=10^8 W/cm^2.

SUMMARY OF THE INVENTION

One object of the present invention is to improve a laser radiation source, preferably for processing materials, as well as an arrangement for processing materials having a laser radiation source and the operation thereof such that an extremely high power density and energy are achieved in a cost-beneficial way, and such that both the beam shape with respect to flexibility, precision and beam positioning as well as the beam power can be exactly controlled even given significantly higher laser powers.

According to the present invention, a laser radiation source is provided for generating laser beams with high power density and higher energy for processing material. A plurality of directly modulatable, diode-pump fiber lasers are provided having outputs arranged in a first ordering pattern. An optical unit is provided connected to the outputs of the fiber lasers wherein laser beams emerging from the outputs of the individual fiber lasers are shaped and aligned such that they impinge onto a processing surface in a second ordering pattern.

Further advantageous developments and improvements with respect to the apparatus for processing materials with the laser beam source and the operation thereof are discussed hereafter.

This laser radiation source comprises a plurality of diode-pumped fiber lasers whose output radiation beams impinge the processing location next to one another and/or over one another or in a point or bundle and thus enables the generation of a processing spot that is designationally variable in shape and size, even given extremely high laser powers and extremely high power densities. According to the invention, these fiber lasers can be implemented as continuous wave lasers or as quality-switched lasers, also referred to as Q-switch lasers, whereby they are advantageously internally or externally modulated and/or

comprise an additional modulator. Q-switch lasers have an optical modulator available to them within the laser resonator, for example an acousto-optical modulator, that, in its opened condition, interrupts the laser effect given a pump radiation that continues to exist. As a result thereof, energy is stored within the laser resonator, this being output as a short laser pulse having high power when the modulator is closed in response to a control signal. Q-switch lasers have the advantage that they emit short pulses having high power, which briefly leads to a high power density. An advantageous elimination of the molten and evaporated material is enabled in the pulsed mode due to the brief-term interruptions in the processing event. Instead of switching the quality, a pulsed mode can also be generated with internal or external modulation.

The processing spot can be designationally modified in shape and size in that different numbers of lasers are provided that can be switched on for shaping the processing spot. It is thereby especially advantageous that the depth of the cut cup can be determined by the laser energy independently of its shape and size. Further, a control of the energy of the individual lasers can also generate any arbitrary beam profile within the processing spot and, thus, any arbitrary profile within the cup as well.

Further advantages of the present invention compared to known laser radiation sources are comprised therein that the infeed of the radiant power from a solid-state laser into an optical fiber can be eliminated but the exit of the fiber laser supplies diffraction-limited radiation that, according to the invention, can be focused onto less than a 10 μm diameter, as a result whereof an extremely high power density is achieved given the greatest possible depth of field.

Given a traditional arrangement with solid-state lasers, the size of the processing spot lies in the region of approximately 100 μm. Given the present invention, thus a power density that is improved by the factor 100 derives, and a design possibility in the area of the processing spot that is improved by the factor 100 derives.

Due to the high precision and due to the processing spot that can be designed in very fine fashion, extremely fine screens, also including the stochastic screens that are also called frequency-modulated screens (FM screens) and, thus extremely smooth edges in lines and written characters can be economically produced, so that rotogravure no longer need be inferior to offset printing in terms of printing quality.

Due to the operating mode of the laser radiation source of the invention, it is also possible to link arbitrary raster widths to arbitrary screen angles and apply arbitrary different screen widths and arbitrary different screen angles at arbitrary locations on the same printing cylinder. Line patterns and text can also be applied independently of the printing screen as long as one sees to sufficient supporting locations for the doctor blade.

One advantage of the invention is that the differences in the data editing for the production of the printing form are reduced to a minimum between rotogravure and offset printing, this yielding substantial cost and time savings. Up to now, the data for the rotogravure are acquired by conversion from the data already present for the offset printing because a signal is required for the drive of the engraving system that defines the volume of a cup, whereby the area of a screen dot is determined in offset printing. As a result of the multiple arrangement of lasers, the laser beam source of the invention makes it possible to vary the area of a cup given constant depth, for which reason it is no longer required to convert the data for offset printing into data for the rotogravure. The data for the offset printing can be directly employed for engraving the rotogravure forms.

Another advantage of the invention is that both the area of a cup as well as the depth can be controlled independently of one another with this laser beam source, this leading to that a greater number of tone value gradations that can be reproducibly generated, this leading to a more stable manufacturing process for the printing cylinders and to an improved printing result.

It is also a critical advantage that the energy can be unproblemmatically transported from the pump source to the processing point with the fiber, namely the fiber laser itself, or with a fiber that is welded on or, respectively, attached in some other way, this yielding an especially simple and space-saving structure.

Another advantage of the invention is that the efficiency of such an arrangement with fiber lasers is significantly higher than the efficiency of solid-state lasers, since absorption efficiencies of more than 60% are achieved for fiber lasers, these lying only at approximately half given traditional dialed-pumped solid-state lasers and being even far lower given lamp-pumped solid-state lasers. Given the required power of several kilowatts for an efficient engraving of rotogravure cylinders, the efficiency of the lasers is of incredible significance for the system costs and the operating costs.

Further, a multiple arrangement of lasers yields the advantage that the outage of a laser is less critical than given a single-channel arrangement. When the only laser that is present given the single-channel arrangement fails during the engraving of a printing cylinder, the entire printing cylinder is unuseable. When, however, a laser fails given a multiple arrangement, then the power of the remaining lasers can, for example, be slightly boosted in order to compensate the failure. After the end of the engraving, the laser that has failed can then be replaced.

The dissertation, "Leistungsskalierung von Faserlasern", Physics Department of the University of Hannover, Dipl.-Phys. Holger Zellmer 20 June 1996, fiber lasers are discussed as being known. These lasers, however, had already been proposed by Snitzer and Köster, without these having been previously utilized for processing materials given high powers. Although powers of up to 100 W can be fundamentally achieved with the lasers described in this dissertation, no useable arrangements are known for utilizing these lasers for purposes of the present invention.

The publication WO-A-95/16294 has already disclosed phase-coupled fiber lasers; however, these are extremely involved in terms of manufacture and

are not suitable for industrial employment. It had hitherto not been recognized to bring lasers of this simple type to high power density and energy in the proposed, simple way and to utilize them for erosive processing of materials.

For example, the resonator length of the individual lasers must be kept exactly constant to the fraction of a micrometer, for which purpose what are referred to as "piezoelectric fiber stretchers" are utilized. As a result of the complex structure, it is likewise not possible to construct the laser unit modularly, i.e. of components that are simple to assemble and to be multiply employed or to replace individual laser components as needed on site as a consequence of the great number of optical components within a phase-coupled laser. Moreover, the optical losses are extremely high, and the pump radiation absorption of the laser-active medium is low, which results in a low efficiency of the arrangement. Although fiber lasers are not particularly susceptible to back-reflections in and of themselves, phase-coupled lasers exhibit a great sensitivity to back-reflections due to their very principle, i.e. when portions of the emitted radiation proceed back into the laser resonator due to reflection or dispersion, as is unavoidable when processing materials. These back-reflections lead to uncontrolled output amplitudes and cause the laser to shut down. Although what are referred to as optical isolators are known, these being intended to attenuate such back-reflections, these involve a number of disadvantages in practice, which, for example, include the optical losses, the high price and the inadequate attenuation properties. The lasers for the purpose of the invention of processing materials need not only exhibit a high power density but also must be able to supply the required energy for cutting out the cups, must be extremely stable in terms of the emitted radiation and must have a very good efficiency.

Further, US-A-5,694,408 has disclosed a laser system wherein a master oscillator generates low-power radiation energy at a specific wavelength, this being optically intensified and it being distributed for further post-amplification onto a plurality of post-amplifiers, in order to then be in turn united to form a common beam, a precise phase readjustment of the individual post-amplified

signals being required for this purpose in order to avoid interferences in the output signal. This requires complicated measuring and control procedures and involved actuating elements, for which purpose, for example, electro-optical phase modulators must be utilized, these being extremely expensive and having to be operated with extremely high voltages.

Further, US-A-5,084,882 discloses a phase-coupled laser system that employs a plurality of fibers or fiber cores in a bundle, the core thereof being, on the one hand, large compared to its cladding or its spacing in order to achieve the phase coupling; on the other hand, this should only have a diameter of a few micrometers since it is a matter of single-mode fibers. This system is mainly provided as an optical intensifier.

Another phase-coupled laser system that is likewise implemented in an extremely complex way and that is composed of a plurality of what are referred to as "sub-oscillators" is disclosed by GB-A-21 54 364 under the title "Laser Assemblies", having already been disclosed in 1984; however, no industrial realizations with such phase-coupled laser systems have become known up to now.

It has also not been previously proposed to combine a number of the initially cited fiber lasers in a simple way, i.e. without a complex phase coupling or the like, to form a compact, rugged and service-friendly radiation source for processing materials and, for example, to employ this for multi-track recording. An inventive, multiple arrangement of such simple lasers that can be cost-beneficially manufactured in quantity in several tracks and levels yields enormous advantages for the purposes of the invention that would certainly not have escaped attention if the invention solution had been known.

A further advantage of fiber lasers is there clearly lower tendency to oscillate when energy proceeds back into the laser. Compared to traditional solid-state lasers, fiber lasers have a resonance overshooting that is lower by an order of magnitude in terms of its transfer function, this having been very positively proven during operation. When processing materials, namely, one cannot always

prevent energy from being reflected from the processing location back into the laser because the melting material is explosively hurled in unpredictable directions and thereby flies through the laser beam before it can be removed and neutralized by particular techniques that are presented in one embodiment of the invention.

A critical advantage of the multiple arrangement of fiber lasers without phase coupling is that the individual lasers behave differently in case of a back-reflection. This is related to the fact that, for example, some of the lasers are not affected at all by a back-reflection and others may possibly be effected only with a delay. The probability is therefore high that oscillations of the individual lasers, if they occur at all, are superimposed such that they have no negative influence on the quality of the results of the engraving.

The laser radiation source of the invention can also be advantageously utilized for all other types of processing materials or transferring materials wherein high power density, high energy and great precision or, too, high optical resolution are important. In addition to engraving rotogravure cylinders having a copper surface, other materials such as, for example, all metals, ceramic, glass, semiconductor materials, rubber or plastics can be processed and/or materials can be stripped from more specifically prepared carrier materials and transferred onto other materials at high speed and with high precision. In addition to those that are uncoated, moreover, rotogravure cylinders, printing plates or printing cylinders that are coated with masks as well as all types of printing forms can also be produced or, respectively, processed at high speed and with high resolution for offset printing, letter press printing, silk screening, flexo-printing and all other printing processes. For example, the offset printing plates having metal coating (bi-metal plates) that are employed for printing extremely large print runs in offset printing and similar materials can be provided with images in an environmentally friendly way, this having been hitherto possible only with etching.

Further, materials can be processed that contain a magnetizable surface, in that the parts of the material magnetized in large-area fashion by a pre-

magnetization process are de-magnetized by briefly heating selected processing points to temperatures that lie above the Curie point, when heated with the inventive laser radiation source. The material provided with images in this way for applications in printing technology can serve as a print master in conjunction with a corresponding toner.

As a result of the high power density of the inventive laser radiation source, it is also possible to directly process chromium. Thus, for example, printing cylinders of copper can already be chrome-plated for rotogravure before the laser engraving, this eliminating a work step after the engraving and benefitting the timeliness. Since the printout behavior of a cup engraved in copper is also better than that of a chrome-plated cup and its volume is more precise, this method also yields even better printing results in addition to the high service life as a result of the remaining chromium layer and the improved timeliness.

The employment of the inventive laser radiation source, however, is not limited to employments in printing technology but can be utilized anywhere that it is important to erode material or change the properties of the material by energy irradiation with lasers given high resolution and high speed. Thus, for example, the aforementioned texture drums can also be produced with the inventive laser radiation source. Further, the patterns of interconnects for printed circuit boards, including the boards for the components, preferably for multi-layer printed circuit boards, can be produced by eroding the copper laminate and allowing the interconnects to stand, and by eroding copper laminate and carriers at the locations of the bores. Further, the surface structure of material surfaces can be partially modified by partial heating. For example, extremely fine structures having the hardness of material surfaces can be produced in large-area fashion in this way, this being particularly advantageous for bearing surfaces since the bearing properties can be intentionally influenced in this way. Further, there are non-conductive ceramic materials at whose surface metal crystallizes out due to energy irradiation, this being capable of being utilized in conjunction with the

inventive laser radiation source for applications that require a high resolution, for example for producing interconnects.

The laser beams can thereby be guided to the processing spot in the greatest variety of ways and can be moved across the material; for example, the material to be processed can be located on a rotating drum past which the radiation source is conducted in relative fashion. However, the material can also be located in a plane over which the laser radiation source or its output radiation is conducted past in relative fashion. In a flat bed arrangement as presented in the aforementioned publication "Der Laser in der Druckindustrie" von W. Hülsbusch, Figure 7-28 on page 431 and as likewise disclosed in the publication EP-A-0 041 241, the radiation source presented therein as argon or He Ne laser or, respectively, as laser light source (4) in Figure 3 of the publication can be replaced by the inventive laser radiation source in order to utilize the advantages of the inventive laser radiation source. Further, the material to be processed can be located within a hollow cylinder over which the laser radiation source or its output radiation sweeps in a relative motion.

Inventively, the output of the laser radiation source can also be implemented with a variable number of tracks whose mutual spacings are variable, preferably similar to a long comb, this moving relative to the material to be provided with images. Such an arrangement is disclosed by US-A-5,430,816. It is disclosed therein to direct the radiation of an excimer laser having a strength of approximately 50 watts onto a bundle of what are referred to as stepped index fibers having diameters of 50 through 800 micrometers and to respectively couple a part of the radiation into the individual fibers. The exit of each fiber is then imaged onto the workpiece via a respective positive lens having a diameter of 60 mm, whereby the spacing between the individual processing points must amount to at least 60 mm and a protective mechanism to prevent contamination is required per positive lens. What is disadvantageous is that only a fraction of the laser energy thus proceeds into the respective fibers. The energy distribution turns out very differently and changes in the exit power derive given movement of the

fibers, for which reason what are referred to as scramblers must be utilized in order to avoid this. These scramblers, however, disadvantageously influence the efficiency of the system and increase the costs. Only relatively imprecise bores having a diameter of approximately 130 micrometers can be produced in plastic with such an arrangement. The pulse rate of the laser is the same for all simultaneously produced bores, so that all bores must be implemented of the same size. Moreover, the system is relatively slow since a boring processing lies between one and two seconds. An arrangement having fiber lasers yields tremendous advantages compared thereto: the speed can be increased by several orders of magnitude and metals can also be processed; the precision is substantially greater since fiber lasers also exhibit a stable output power given movement of the laser fibers; and bores having diameters below 10 micrometers can also be unproblemmatically produced. Since each fiber laser can be separately modulated, different processing patterns are possible. Further, the end sections of the fiber lasers can be unproblemmatically implemented smaller than 2.5 mm in diameter, this enabling a clearly smaller spacing between the processing tracks. As a result thereof, it is also possible to employ a shared protective mechanism to prevent contamination of the optics.

Another example for the application of the inventive laser beam source wherein the material is preferably arranged in a plane derives in the semiconductor industry in the processing of what are referred to as wafers, i.e. usually circular disks of suitable semiconductor material that, for example, are incised or cut or can be provided with all conceivable patterns in the surface, of a type that could previously be manufactured only by time-consuming chemical etching processes that were also not environmentally friendly.

For the multi-channel cutting and in sizing of materials, a simplified embodiment of the laser radiation source is inventively possible, as disclosed in the German Patent Application P 198 40 936.2 of the assignee, "Anordnung zum mehrkanaligen Schneiden und Ritzen von Materialien mittels Laserstrahlen".

A further inventive application of the laser radiation source is established in the manufacture of monitors and displays. For example, the apertured masks for color picture screens as well as the masks of what are referred to as flat picture screens or LCD displays can be manufactured in a more environmentally friendly way with laser processing than with the chemical etching processes that were previously employed, in that the inventive laser radiation source is applied.

A considerable advantage of the inventive laser radiation source is that it has a small volume and has a flexible connection, namely the laser fibers or fibers connected thereto between the pump source and the exit of the radiation at the processing location and thus allows all conceivable operating positions of the laser radiation source or of its beam exit. There are therefore also no limitations for the spatial arrangement of the processing surface, since they can be arranged in an arbitrary attitude in space.

Another advantage of the invention is comprised therein that the radiation beam of the individual lasers with defined values in beam diameter, beam divergence centering and angular direction can be exactly and durably acquired in a terminating section (terminator), as a result whereof a fabrication-suited and service-suited arrangement for forwarding the laser radiation onto the processing surface can be created. Inventively, the radiation beams can thereby be coupled into the fiber dependent on the application, for example as pump spot and/or can be coupled out as parallel laser beam, can diverge at the exit location or, for example, can be focused in a certain distance from the exit point. There is thus a desire to fashion the terminator as small as possible and to provide it with one or more fits as a reference surface or reference surfaces for the alignment of the laser beam.

According to the invention, this is achieved in that the optical fibers are set in the terminator and the position of the optical fibers and/or the position of the emerging radiation beam is exactly adjusted. On the basis of the exact adjustment and of an inventive, correspondingly spatially small embodiment of the terminators which can also be attached to one another in an especially simple way

as a result of a special shaping, it becomes possible to combine the radiation beams of a plurality of fiber lasers and focus them such that the respectively encountered object is achieved and, at the same time, an economical manufacture as well as a cost-beneficial maintenance of the laser radiation source is enabled.

The invention is explained in greater detail below on the basis of Figures 1 through 44a.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic illustration of the laser radiation source;

Fig. 2 is a fundamental illustration of the fiber laser (prior art);

Fig. 2a is an attenuated illustration of the fiber of the fiber laser (prior art);

Fig. 3 is a cross-section through an arrangement for processing material with a laser radiation source of the invention;

Fig. 4 is an illustration of a laser gun for the inventive laser radiation source having a multiple arrangement of fiber lasers;

Fig. 4a is a perspective illustration relating to Fig. 4;

Fig. 4b is a version of Fig. 4;

Fig. 4c is a further version of Figs. 4 and 4b;

Fig. 5 is an example of a terminator for the outfeed of the radiation from a fiber or, respectively, from the fibers of a fiber laser;

Fig. 5a is an example of a multiple arrangement for a plurality of terminators;

Fig. 5b is an example of a terminator having adjustment screws;

Fig. 5c is a cross-section through the terminator according to Fig. 5b in the region of the adjustment screws;

Fig. 6 is an example of a terminator having spherical adjustment elements;

Fig. 6a is a cross-section through the terminator according to Fig. 6 in the region of the spherical adjustment elements;

Fig. 7 is an example of an embodiment of a terminator having a conical fit for insertion into a mount;

Fig. 8 is an example of a multiple mount for a plurality of terminators;

Fig. 8a shows the rear fastening of the terminators according to Fig. 8;

Fig. 9 is an example of an embodiment having quadratic cross-section;

Fig. 9a is a cross-section through the terminator according to Fig. 9;

Fig. 10 is an example of a terminator having rectangular cross-section and a trapezoidal plan view;

Fig. 10a is a longitudinal section through the terminator according to Fig. 10;

Fig. 10b is a cross-section through the terminator according to Fig. 10;

Fig. 11 is an example of a terminator having trapezoidal cross-section;

Fig. 11a is an example of a terminator having triangular cross-section;

Fig. 12 is an example of a terminator having honeycomb-shaped cross-section;

Fig. 13 is a modular implementation of the fibers of the fiber laser according to Fig. 1;

Fig. 14 is an example of the infeed of the pump energy into the fibers of the fiber laser according to Fig. 13;

Fig. 15 is an example of a fiber laser having two outputs;

Fig. 16 is an example of the merging of two fiber lasers;

Fig. 17 is a schematic illustration of the beam path through an acousto-optical deflector or, respectively, modulators;

Fig. 18 shows blanking out unwanted sub-beams of an acousto-optical deflector or, respectively, modulators;

Fig. 18a is an arrangement having an electro-optical modulator ;

Fig. 19 is a plan view onto a four-channel acousto-optical modulator;

Fig. 19a is a section through the modulator according to Fig. 19;

Fig. 20 is a schematic beam path for a plan view for Fig. 4;

Fig. 21 is a schematic beam path for a plan view for Fig. 4b;

Fig. 22 is a schematic beam path for a plan view for Fig. 4c;

Fig. 23 shows a beam path for terminators that are arranged at an angle

relative to one another;

Fig. 24 is a version of Fig. 23 that contains a multi-channel acousto-optical modulator;

Fig. 24a is a version for Fig. 24;

Fig. 25 is an intermediate image for matching the fiber lasers or, respectively, their terminators to, for example, the modulator;

Fig. 26 shows the merging of twice for tracks of the beam path from terminators with a strip mirror arrangement;

Fig. 26a is a plan view for Fig. 26;

Fig. 27 is a view of a strip mirror;

Fig. 27a is a sectional drawing through the strip mirror according to Fig. 27;

Fig. 27b is another example of a strip mirror;

Fig. 28 shows the combining of twice for tracks of the ray beam from terminators with a wavelength-dependent mirror;

Fig. 28a is a plan view of Fig. 28;

Fig. 29 is an arrangement of a plurality of terminators in a plurality of tracks and in a plurality of planes;

Fig. 30 is an arrangement of a plurality of terminators in a bundle;

Fig. 31 is a sectional view through the ray beam from the terminators of the fiber lasers F1 through F3 according to Fig. 29 or Fig. 30;

Fig. 32 is an arrangement having a plurality of terminators in a plurality of tracks and a plurality of levels having a cylindrical optics for matching, for example, to the modulator;

Fig. 33 is a modification of Fig. 32;

Fig. 34 shows a mouthpiece for the laser gun with connections for compressed air and for extracting the material released by the beam;

Fig. 35 shows a turning of the laser gun for setting the track spacings;

Fig. 36 is an illustration for generating four tracks with an acousto-optical multiple deflector or multiple modulator;

Fig. 36a is a spatial presentation of an acousto-optical multiple deflector or multiple modulators;

Fig. 36b is an expanded embodiment related to Fig. 36a;

Fig. 36c is a plan view of Fig. 36b;

Fig. 37 is an illustration for generating multiple tracks with the assistance of an acousto-optical multiple deflector or multiple modulator;

Fig. 38 is an advantageous arrangement for avoiding reflections back into the lasers;

Fig. 39 shows a lens that has coolant flowing around it;

Fig. 39a is a section through a mount 4 an objective lens;

Fig. 40 shows a fiber laser or a fiber that have been clearly reduced in cross-section at their exit end;

Fig. 40a is a plan view onto the end of the fiber laser or the fiber according to Fig. 40;

Fig. 40b is a side view of the fiber end wherein the axes of the emerging ray beams proceed nearly parallel;

Fig. 40c is a side view of the fiber end wherein the axes of the emerging ray beam overlap outside the fiber bundle;

Fig. 40d is a side view of the fiber end wherein the axes of the emerging ray beams overlap within the fiber bundle;

Fig. 41 shows an arrangement of fiber lasers or fibers according to Fig. 40 in a plurality of tracks and levels;

Fig. 42 shows a further embodiment of the laser radiation source;

Fig. 42a shows a further embodiment according to Fig. 42;

Fig. 42b is a sectional view of Fig. 42a;

Fig. 42c is an illustration of a robot;

Fig. 43 shows a flat bed arrangement having the inventive laser beam source;

Fig. 43a is an addition to Fig. 43;

Fig. 43b is a sectional drawing through an arrangement for removing the material released during the processing;

Fig. 44 is a hollow bed arrangement having the inventive laser beam source; and

Fig. 44a shows an addition to Fig. 44.

DESCRIPTION OF THE PREFERRED EMBODIMENT

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the preferred embodiment illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is there3by intended, such alterations and further modifications in the illustrated device, and such further applications of the principles of the invention as illustrated therein being contemplated as would normally occur to one skilled in the art to which the invention relates.

Fig. 1 shows a laser radiation source 1 that is composed of a plurality of diode-pumped fiber lasers 2, also called fiber lasers, inventively implemented preferably as modules, these being charged with electrical energy by a preferably modular supply 32 that is largely converted into laser radiation. Further, a controller 33 is provided via which the modulation of the radiation is undertaken and that sees to the interaction of the laser radiation source with its periphery. The output rays of the laser enter into an optical unit 8 at the radiation entry 9 and emerge from the optical unit at the radiation exit 10. The job of the optical unit 8 is to shape the laser radiation to form a processing spot 24 on a processing surface 81; however, the laser radiation can also be directly directed on to the processing surface without the optical unit.

Figs. 2 and 2a show the fundamental structure of a fiber laser arrangement 2. In Fig. 2, the energy of a pump source such as, for example, a laser diode, called a pump source 18 here, is shaped via an infeed optics 3 to form a suitable pump spot 4 and is coupled in to the laser fiber 5. Such pump sources are disclosed, for example, in German Patent Application P 196 03 704 of the

assignee. Typical pump cross-sections of the laser fibers lie approximately between 100 µm and 600 µm in diameter given a numerical aperture of approximately 0.4. The laser fiber 5 is provided with an infeed mirror 7 at the infeed side 6 that allows the pump radiation to pass unimpeded but which exhibits 100% reflection for the laser radiation. The infeed mirror 7 can be secured to the fiber end with a suitable mount or by gluing; however, it can also be realized on the fiber end by direct vapor-deposition of a suitable layer as employed given infeed mirrors for lasers. An outfeed mirror 12 that is partially reflective for the laser radiation is attached to the outfeed side 11 of the laser fiber 5, the laser radiation 13 being coupled out through the outfeed mirror 12. Advantageously, the outfeed mirror exhibits 100% reflection for the pump radiation. As a result thereof, the remaining pump radiation is reflected back into the optical fiber, which is advantageous since the pump energy is utilized better and, further, does not represent a disturbing factor in the application of the laser radiation. The outfeed mirror can, like the infeed mirror, likewise be produced by vapor-deposition.

The infeed event of the pump radiation into the pump cross-section 14 of the laser fiber 5 is shown in greater detail in Fig. 2a. The energy in the pump spot 4 excites the laser radiation in the core 15 of the laser fiber 5 on its way through the fiber. The pump core 16 is surrounded by a cladding 17. The core of the laser fiber that is approximately 5 µm through 10 µm thick is doped mainly with rare earths.

The relatively large pump cross-section 14 simplifies the infeed of the pump energy and enables the use of a connection between pump source and laser fiber that is simple to release, as shown in Figs. 13 and 14. The terminator of the laser fiber at the side of the pump source can thereby be advantageously structurally the same as the terminator at the outfeed side; however, it need not be. A precise blood-type connection between pump source and laser fiber offers considerable advantages in the manufacture of the fiber laser and in case of service. The laser fiber, however, can also be firmly connected to the pump

source to form a laser module. As a result of the intentionally manufactured, extremely small fiber core diameter, the fiber laser supplies a practically diffraction-limited laser radiation 13 at the exit.

Fig. 3 shows a cross-section through one of the inventive embodiments of an arrangement for processing materials with the inventive laser radiation source 1. A drum 22 is rotatably seated in a housing 21 and is placed into rotation by a drive (not shown). A laser gun 23, which is conducted along the drum in the axial direction with a carriage (not shown), is located on a prism (likewise not shown).

The laser radiation emerging from the laser gun 23 impinges the surface of the drum at the processing location in the processing spot 24. Either the surface of the drum as well as a material clamped onto the drum surface can be processed. The fiber lasers, whose laser fibers 5 are respectively wound to a form, for example, an air-permeated coil 25, are supplied into the laser gun 23 with the inventive terminators 26, 94. Advantageously, however, passive single-mode fibers or other passive optical fibers, referred to in brief as fibers 28, can also be welded to the fiber lasers or coupled thereto in some other way before the terminators 26, 94 are attached, as described in Figs. 15 and 16.

The pump sources 18 of the fiber lasers are attached on a cooling member 27 that diverts the waste heat via a cooling system 31. The cooling system 31 can be a matter of a heat exchanger that delivers the waste heat to the surrounding air; however, it can also be a matter of a cooling unit. The laser gun 23 can also be connected to the cooling system, but this is not shown. The driver electronics for the pump sources 18, which belong to the supply 32 (not shown in further detail), are preferably situated on the cooling member. A machine control is provided for the drives but is not shown in Fig. 3. The structure of the pump sources, fiber laser and corresponding power electronics is preferably modularly implemented, so that corresponding pump sources and power modules of the driver electronics that are separate or combined into groups belong to the individual fiber lasers, these being capable of being connected to one another via a bus system. As explained in greater detail in Fig. 13 and Fig. 14, the laser fibers 5 and the pump

sources 18 can be connected to one another via a releasable connection. It is also possible to couple a slight part of the pump radiation out of the laser fiber 5, for example as a result of a slight injury to the cladding 14, and to conduct this via an optical fiber onto a measuring cell in order to offer a signal therefrom that can be employed for the control or, respectively, regulation of the pump radiation.

The modulation signals for the laser radiation are generated in the controller 33 and the interaction of the laser radiation source with the machine control and with the supply 32 as well as the executive sequence of the calibration events as well as of the control and regulation events are managed in the controller 33. A safety circuit (not shown), for example, switches the pump sources permanently off when there is danger.

Although a horizontally seated drum is shown in Fig. 3, the drum being arranged in any arbitrary attitude since the inventive laser radiation source is completely directionally insensitive in terms of its attitude and is very compact in terms of structure and, moreover, since the laser fibers 5 of the fiber laser or fibers 28 coupled to the laser fibers can be arbitrarily laid; for example, the shaft of the drum can also be seated vertically or inclined from the perpendicular, which yields an especially small floor space. As a result thereof, moreover, the operation of a plurality of arrangements or a system having a plurality of drums is possible on the same floor space as would be required by an arrangement having a horizontally seated drum. As a result thereof, the printing forms can be manufactured faster; in particular, all printing forms for a color set can be produced in a single, parallel pass, which is advantageous especially with respect to the uniformity of the final result. Further, an automatic charging with printing forms for provision with images can be realized better given a system erected on a small floor space than given a spatially larger system. One or more laser radiation sources and, additionally, one or more further lasers can be directed onto the same printing form in order to accelerate the production thereof. One advantage of the multi-track arrangement having the very fine and precise tracks is that potential seams are clearly less disturbing then when recording is carried out with coarser

tracks. As described under Fig. 37, further, the position of the tracks can be precisely re-adjusted, so that residual errors become clearly smaller than a track width. The inventive laser radiation sources can thereby be preferably utilized for processing the finer contours and the further laser or lasers can be utilized for processing rougher contours, which can be particularly employed given printing forms that, for example, are composed of plastic or rubber.

Instead of one or each of the provided fiber lasers 2, it is conceivable to provide a laser system with a terminator into the laser radiation source and alternative supply to the laser gun 23, whereby the fiber laser described in detail under Fig. 2, however, represents the more cost-beneficial solution. When processing materials, namely, if the radiant power of a plurality of lasers that are not coupled to one another and that naturally emit with a slight wavelength difference are directed onto a processing spot, a phase equality of the individual lasers can be foregone and an expensive control and regulation technology for a phase coupling that is susceptible to malfunction can be avoided.

Such a laser system that, for example, is disclosed by US-A-5,694,408 contains an optical post-amplification and comprises a radiation output composed of a fiber. A terminator is described in greater detail later in one of the Figures 5, 5a, 5b, 5c, 6, 6a, 7, 9, 9a, 10, 10a, 10b, 11, 11a or 12.

Instead of employing the laser system disclosed by US-A-5,694,408, it is also conceivable to employ a phase-coupled laser system according to US-A-5,084,882. An image of the fiber bundle then results on the processing surface as the respective processing spot. Alternatively, a single-mode fiber could be welded to each fiber at the exit of the bundle, this being provided with the respective terminators, and supply the laser gun. However, it is extremely difficult and complicated to manufacture such phase-coupled laser systems and they would be correspondingly expensive. Up to now, such phase-coupled laser systems have also not been commercially available.

Fig. 4 is a section through an applied example of a laser gun having sixteen fiber lasers that are coupled via terminators 26 and having a modulation

unit composed of two multi-channel acousto-optical modulators 34. The laser gun is a multi-part receptacle for the adaptation of the optical unit and contains mounts 29 (Fig. 4a) with fitting surfaces for the fits of the terminators 26, means for combining the individual laser beams, the modulation unit, a transmission unit for the transmission of the laser radiation that is intended to produce a processing effect onto the processing surface, and an arrangement for neutralizing the laser radiation that is not intended to produce a processing effect. An arrangement for removing the material eroded from the processing surface can be arranged at the laser gun; this, however, can also be arranged in the proximity of the processing surface in some other way.

Fig. 4a shows a perspective illustration relating to Fig. 4.

Fig. 4b shows a modification of Fig. 4 wherein the ray beams of the individual fiber lasers do not proceed parallel as in Fig. 4 but at an angle relative to one another; this, however, cannot be seen from the sectional view in Fig. 4b and is therefore explained in greater detail in Figs. 21, 22 and 24.

Fig. 4c shows a modification of Fig.4b that enables an advantageous, significantly more compact structure as a result of a differently implemented transmission unit.

Fig. 4 shall be explained in detail first with the assistance of Fig. 4a. These explanations apply analogously to Figs. 4b and 4c.

In a housing 35, 4 fiber lasers F_{HD1} through F_{HD4}, F_{VD1} through F_{VD4}, F_{HR1} through F_{HR4}, F_{VR1} through F_{VR4} via terminators 26 with mounts 29 (Fig. 4a) are arranged in respectively four tracks of one beam packet H, being arranged side-by-side in a plane. The embodiment of the terminators 26 employed in Fig. 4 is described in greater detail in Fig. 9. The terminators should preferably be inserted gas-tight into the housing 35, to which end seals 36 (Fig. 4a) can be employed. Instead of the terminators shown in Figs. 4 and 4a, differently shaped terminators can also be employed, as described in Figs. 5, 5a, 5b, 5c, 6, 6a, 7, 9, 9a, 10, 10a, 10b, 11, 11a and 12, when corresponding mounts 29 are provided in the housing 35. However, as also described under Fig. 3, single-mode fibers or other fibers 28

can be attached to the fiber lasers before the terminators 26 are attached. However, an arrangement of the laser fibers 5 or fibers 28 according to Figs. 40, 40a, 40b, 40c, 40d and 41 can also be employed. For example, the fiber lasers F_{HD1} through F_{HD4} or, respectively, F_{VR1} through F_{VR4} should have a different wavelength than the fiber lasers F_{VD1} through F_{VD4} or, respectively, F_{HR1} through F_{HR4}. For example, F_{HD1} through F_{HD4} and F_{VR1} through F_{VR4} should have a wavelength of 1100 nm whereas F_{VD1} through F_{VD4} or, respectively, F_{HR1} through F_{HR4} should have a wavelength of 1060 nm, which can be achieved by a corresponding doping of the laser-active core material of the laser fibers 5. However, all fiber lasers can also exhibit different wavelengths when they are correspondingly compiled.

As explained in greater detail in Figs. 28 and 28a, the beam packets of the fiber lasers F_{HD1} through F_{HD4} are united with those of the fiber lasers F_{VD1} through F_{VD4} and the beam packets of the fiber lasers F_{VR1} through F_{VR4} are united with those of the fiber lasers F_{HR1} through F_{HR4} to form a respective beam packet F_{D1} through F_{D4} as well as F_{R1} through F_{R4} (Fig. 4a) via wavelength-dependent mirrors 37 as means for the combining. There are also other possibilities of influencing the wavelength of the fiber lasers; for example, wavelength-selecting elements such as Brewster plates, diffraction gratings or narrowband filters can be introduced in the region of the laser fibers between infeed mirror 7 and outfeed mirror 12. It is also possible to provide at least one of the two laser mirrors 7 or 12 with a mirror layer of a type that is adequately highly reflective only for the desired wavelength. The inventive execution of the beam merging, however, is not limited to the employment of fiber lasers with different wavelengths. In addition to fiber lasers that have no privileged direction in the polarization of the laser emission that is output, fiber lasers can also be employed that output a polarized laser emission. When the wavelength-dependent mirror is replaced by a mirror that is polarization-dependent such that it allows one polarization direction to pass whereas it reflects the other polarization direction, only two differently polarized laser types need be employed in order to unite the two with the

polarization-dependent mirror. In this case, the employment of the terminator 26 according to Fig. 9 having a quadratic cross-section is especially suitable, since the one or the other polarization direction can be respectively produced with the same fiber laser by turning the terminator by 90° before being mounted into the housing 35.

A particular advantage of the combining of a plurality of lasers to form a single spot, namely to each of the individual processing points B_1 through B_n (for example B_1 through B_4 in Figs. 20 through 22) is that a higher power density is achieved given a predetermined spot size on the processing surface 81.

The laser emission of the individual fiber laser can also be distributed onto a plurality of terminators, this being described in Fig. 15. This is particularly useful when materials are to be processed that manage with a low laser power or when the power of an individual fiber laser is adequately high. In such a case, it is conceivable that a laser gun 23 is equipped with only four terminators, for example F_{HD1} through F_{HD4}, for this purpose, F_{HD1} and F_{HD2} thereof, for example, being supplied by one fiber laser and F_{HD3} and F_{HD4} being supplied by a further fiber laser according to Fig. 15. When the principle described in Fig. 15 is applied twice, all four tracks F_{HD1} through F_{HD4} can be supplied by one fiber laser, this leading to an extremely cost-beneficial arrangement, particularly since further component parts such as wavelength-dependent mirrors and strip mirrors can be eliminated and, thus, an especially economical embodiment of the laser radiation source can be created.

By omitting fiber lasers or, respectively, tracks, further, the acquisition costs for such an arrangement can be lowered as needed and fiber lasers can be retrofitted later as needed. For example, one can begin with one fiber laser and one track. The lacking terminators of the fiber lasers that are not introduced are replaced for this purpose by structurally identical terminators that, however, do not contain a through opening and no laser fibers and only serve for termination in order to close the housing 35 as though it were equipped with all terminators.

However, the laser radiation of a plurality of fiber lasers can also be combined and conducted into a single terminator, this being described in Fig. 16. For example, one can work with a plurality of fiber lasers combined in this way and with one track when, as described, the missing terminators are replaced by structurally identical terminators that, however, do not contain a through opening and no laser fibers in order to close the housing 35 as though it were equipped with all terminators.

Immediately after the ray beam has left the respective terminator, a part of the laser emission can be coupled out via a beam splitter (which, however, is not shown) and can be conducted onto a measuring cell that is not shown in the Figs. in order to produce a measured quantity therefrom that can be used as comparison value for a control of the output power of each and every fiber laser. However, laser emission can also already be coupled out of the laser fiber for the acquisition of a measured quantity before the terminator, this also not being shown.

The plurality of planes wherein the terminators are arranged is not limited to the one plane as described. For example, arrangements having three planes are recited in Figs. 29, 32, 33 and 41. An arrangement having two planes is shown in Fig. 38.

The respective beam packets of the fiber lasers are modulated via a respective four-channel acousto-optical modulator 34 whose functioning and embodiment is explained in greater detail in Figs. 17, 18, 19 and 19a. Using the acousto-optical modulator 34, which is a deflector in terms of principle, the unwanted energy in the case illustrated here is deflected out of the original beam direction I_0 into the beam direction I_1 (Fig.4a), so that it can be simply intercepted later in the beam path and neutralized. The modulation can preferably occur digitally, i.e. a distinction is made between only two conditions in the individual modulator channels, namely “on” and “off”, this being especially simple to control; however, it can also occur in analog fashion since the laser power in each modulator channel can be set to arbitrary values. The modulation is not limited thereto that the energy from the beam direction I_0 is employed for the processing

and the energy from the direction I_1 is neutralized. Figs. 36, 36a, 36b, 36c and 37 recite examples wherein the beam direction 1_1 that is diffracted off is employed for processing and the energy from the direction I_0 is neutralized. Further, a slight part of the modulated radiant power of the individual modulator channels can be forward onto a respective measuring cell via a beam splitter (not shown) in order to generate a measured quantity that is used as a comparison value in a control circuit for the exact regulation of the laser energy of each track on the processing surface.

The multi-channel acousto-optical modulator 34 is preferably secured on a cylindrical modulator housing 41 that is rotatably seated in an opening 48 in the housing 35. After the modulator housing has been adjusted to the required Bragg angle α_B, the modulator housing is fixed with a connection 42. A seal 43 sees to it that each modulator housing terminates gas-tight relative to the housing 35. A specifically prepared printed circuit board 171 projects from the modulator housing 41 into the interior space 44 of the housing 35, electrical connections to the piezo-electric transducers 45 being produced thereover. The preferred embodiment of the modulators is described in greater detail in Figs. 19 and 19a.

After passing through the acousto-optical modulators, the beam packets F_{D1} through F_{D4} and F_{R1} through F_{R4} are conducted to a strip mirror 46 that is described in greater detail in Figs. 26, 26a, 27, 27a and 27b. The beam packets F_{D1} through F_{D4} is arranged with respect to the strip mirror 46 such that it can pass through the strip mirror unimpeded. The laser beam bundles of the beam packet F_{R1} through F_{R4}, however, are offset by half a track spacing compared to the beam packet F_{D1} through F_{D4} and impinge the strips of the strip mirror arranged in strip-shaped fashion. As a result thereof, they are redirected in terms of their direction and now lie in one plane with the laser beam bundles F_{D1} through F_{D4}. An eight-track arrangement thus derives, whereby two lasers of different wavelengths are also superimposed in each track, so that a total of sixteen lasers have been merged and take effect. Two beams I_1 that have been diffracted off in the acousto-optical modulator 34 are located above this plane I_0. Given a different adjustment of the

acousto-optical modulator 34, the rays that are diffracted off can also lie under the plane of I_0, as shown in Figs. 4b and 4c.

A significant advantage of the inventive arrangement is that the symmetry axis of the beam packets F_{HD1} through F_{HD4} and F_{D1} through F_{D4} lie on the axis of the housing 35 that is defined by the bore 47, and the beam axes of the corresponding beam packets respectively lie parallel or at a right angle to this axis, which allows a simple and precise manufacture. However, it is also possible to arrange the beam packets asymmetrically and at different angles. Further, it is possible to correct small differences in the position of the beam packets by adjusting the wavelength-dependent mirrors 37 and of the strip mirror 46. It is possible to still re-adjust the terminators in position after they are mounted and in terms of their angular allocation, for example for individual optimization of the Bragg angles in the individual channels; this, however, is not shown in the Figures.

It lies within the scope of the invention that the plurality of tracks is reduced but can also be increased further; for example, by joining respectively eight instead of four terminators that are connected to fiber lasers to form a beam packet, a doubling of the number of tracks can be undertaken. For this purpose, two eight-channel acousto-optical modulators would have to be utilized. Acousto-optical modulators having 128 separate channels on a crystal can be commercially obtained.

Within the framework of the invention, it is likewise possible to arrange the fiber lasers in different planes for increasing the power per track and to superimpose their power on the processing surface, this being explained in greater detail in Figs. 29, 31, 32, 33 and 41 and/or to arrange a plurality of fiber lasers in bundles in order to superimpose their energy on the processing surface, this being described in Figs. 30 and 31.

Another possibility for increasing the number of tracks is described in Fig. 37.

Directly modulatable fiber lasers can also be utilized, this being described in greater detail in Fig. 23. In this case, the acousto-optical modulators are omitted and an especially simple structure derives.

Operation with a plurality of tracks of lasers and a plurality of lasers in a track enables high processing speeds given low relative speed between the laser gun and the workpiece. The processing speed can also thus be optimally adapted to the time constant of the heat elimination of the material. Given a longer operating time, too much energy uselessly flows off into the environment.

The housing 35 is closed gas-tight with a cover and a seal, neither being shown in the Figures. A cylindrical tube 51 is flanged to the housing 35 in the region of the bore 47 and is sealed via a seal 52. The cylindrical tube contains as an optical transmission unit two tubes 53 and 54 each having a respective optical imaging system that image eight laser beam bundles F_{D1} through F_{D4} and F_{R1} through F_{R4} at the beam exit 10 (Fig. 1) onto the processing surface in the correct scale. Two optical imaging systems are preferably arranged following one another, since an extremely great structural length or a very small distance between the objective lens and the processing surface would otherwise derive, both being disadvantageous since a long beam path must be folded with mirrors and too small a spacing between objective lens and processing surface could lead to a high risk of contamination for the objective lens.

The beam path is shown as a side view in Fig. 4. The fundamental beam path is shown in Fig. 20 as a plan view for the beam packet F_{HD1} through F_{HD4}. The wavelength-dependent mirrors, the modulators and the strip mirrors are not shown therein. The Figures mainly show plano-convex lenses; however, it is also possible to utilize other lens forms such as, for example, biconvex or concave-convex lenses or lenses having an aspherical shape in all figures. Lens systems that are respectively composed of a plurality of lens combinations can also be employed.

In order to transmit the laser energy as efficiently as possible and keep the heating of the optical components within limits, all optical surfaces occurring in

the various embodiments of the laser radiation source are anti-bloomed with outmost quality for the wavelength range coming into consideration. The optical imaging systems can preferably be telecentrically implemented.

There are also other advantageous solutions for the transmission unit in order to shorten the structural length of the transmission unit and thereby nonetheless achieve a large spacing between the objective lens and the processing surface, as is shown in even greater detail in, among others, Figures 4b and 4c. The lenses 55 and 56 can be connected to the tube 53 by screwed connections or by gluing; however, they can also be preferably metallized at their edges and soldered to the tube 53. The same is true of the lenses 57 and 61 in the tube 54. A gas-tight seal of the lenses and a good heat transmission from the lenses to the tubes thus derives. The tube 54 is preferably terminated gas-tight relative to the cylindrical tube 51 with a seal 62. With respect to tightness and cleanliness, the same conditions apply to the space 63 as apply to the space 44 and, likewise, to the spaces 64 and 65 within the tubes 53 and 54. The chambers 66 and 67 are preferably connected to the spaces 44 and 63 via bores 71. The tubes 53 and 54 can preferably comprise openings 72.

An intercept arrangement 73 for neutralizing the laser radiation that is not intended to produce any processing effect on the processing surface and that comprises a high-reflectivity mirror 74 and a dispersion lens (concave lens) 75 projects into the space 63. The principle of the intercept arrangement 73 is described in greater detail in Fig. 18. The intercept arrangement 73 is introduced with a seal 76, and the concave lens 75, which can also be replaced by some other optical element, for example a glass plate, is glued into the intercept arrangement or is preferably metallized at an image edge zone and soldered to the intercept arrangement for better heat elimination. The space 63 is thus closed off gas-tight from the environment. What derives as a result of the described techniques is that the entire interior of the laser gun is sealed gas-tight from the environment. The spaces 44, 63, 64 and 65 and the chambers 66 and 67, i.e. the entire interior of the laser gun, can be preferably evacuated or filled with a protective atmosphere. The

spaces and chambers should be as free as possible of components that output gases or particles because dirt could otherwise settle on the highly stressed optical surfaces, which would lead to a premature failure of the arrangement. The seals to be employed should not give off any particles or gases. Ultimate cleanliness of the parts to be assembled and of the environment has great value associated with it during assembly until the laser gun has been closed. After the closing of the laser gun 23, an evacuation of the entire interior can be undertaken via the valve 77 or a protective atmosphere can be filled in. The advantage of filling the interior with protective atmosphere is that it is simpler to replenish in that a gas bottle (not shown) is connected to the valve 77 during operation via a pressure-producing valve, gas being capable of being refilled into the housing therefrom as needed. Another advantage is that, when a terminator is to be removed from the housing for the replacement of a fiber laser and is to be replaced by another or when the housing or, respectively, the cylindrical tube must be opened by the user for some reason or other, a slight quantity of the protective atmosphere can be allowed to flow through the housing during the procedure in order to thus prevent the penetration of dirt particles into the protected space. A slight quantity of the gas can also be allowed to constantly flow through the housing and escape such through openings, preferably in the proximity of the objective lens. This flow also prevents a contamination of the objective lens by dirt particles that are released during the processing event (Fig. 39a). The evacuation or the filling with protective atmosphere can also be foregone when a shorter service life of the laser radiation source is accepted.

It is advantageous in the arrangement according to Fig. 4 that the angle between the beam packets of the original beam direction I_0 of the acousto-optical modulator and the beam direction I_1 that is diffracted off is noticeably increased by the imaging system composed of the lenses 55 and 56, so that it is simple to intercept the unwanted radiation packet of the deflected beam direction with the highly reflective mirror 74 at the intercept arrangement 73. The mirror 74 is preferably fabricated of metal and is provided with a highly reflective layer in

order to keep the heating as a consequence of absorbed laser energy low. For better heat elimination, it is connected via a strong flange of the intercept arrangement 73 to the tube 51. However, the intercept arrangement can also be foregone when the highly reflective mirror is replaced with an optical component such as, for example, a lens that slightly modifies the optical properties of the laser radiation to be intercepted such that the focus of the radiation that is diffracted off is different from the focus of the radiation employed for processing the material. If the radiation to be intercepted would then also be conducted onto the processing surface, the radiation to be intercepted would not have the required power density in order to erode material but would be uselessly absorbed and reflected. The advantage of the arrangement according to Fig. 4 is that low demands are made of the optical components in the two tubes. The two tubes could also be implemented completely the same. Another advantage is that the axes of the terminators 26 lie parallel to one another. The distance between the objective lens 61 and the processing surface 81 dare not be too small, so that particles that fly off from the material surface do not proceed onto the objective lens. When it is contaminated, it then absorbs the laser energy that passes, is destroyed, and is thus unuseable. In order to prevent the contamination, a special mouthpiece 82 is arranged between the objective lens 61 and the processing surface 81, this being described in greater detail under Fig. 34.

The laser gun 23 of the laser radiation source is rotatable around the optical axis that is identical to the axis of the cylindrical tube 51, 95 within the arrangement for processing materials (Fig. 3), for example on a prism 83, and is seated displaceable in the direction of the optical axis and fixed in its position with a strap retainer 85 or with a plurality of strap retainers. As a result thereof, an exact delivery of the laser gun to the processing surface 81 is possible. A plate 86 that comprises openings 87 through which a coolant can be pumped is located outside the prism 83. The job of this plate 86 is to intercept and divert the laser energy intercepted from the beam path of the transmission unit, this being shown in greater detail in Fig. 18. A heat dam that, however, is not shown in the Figs., is

located between the plate 86 and the tube 51, 95, 113. The plate is connected to the tube 51, 95, 113 via insulating flanges 91. The flanges 91 also prevent the emergence of laser radiation.

By turning the laser gun 23 around its optical axis, the track spacing of the laser tracks on the processing surface 81 can be modified, this being shown in greater detail in Fig. 35. It lies within the scope of the invention that the turning of the laser gun for setting the track spacing as well as the setting of its spacing from the processing surface can be implemented not only exclusively manually but with the assistance of a suitable, preferably electronic control and/or regulation. Suitable measuring devices (not shown) can also be inventively provided for this purpose, these being located in the proximity of the processing surface and being capable of being approached by the laser gun as needed. A further possibility for adjusting the track spacing is described in Figs. 36, 36a, 36b, 36c and 37. A manually or motor-adjustable vario-focusing optics can also be utilized for setting the track spacing. Such a vario-focusing optics, in addition to permanently arranged lenses, preferably has two movable lens system, whereby an adjustment of the first lens system mainly effects an adjustment of the imaging scale, with which the track spacing can be influenced, and whereby an adjustment of the second lens system mainly effects an adjustment of the focusing. An iterative setting can be undertaken for optimizing track spacing and best focus. It is also possible to arrange a displaceable lens (not shown) having a long focal length, preferably between the lenses 57 and 61, with which the focusing of the processing points on the processing surface can be finely readjusted without having to displace the radiation source because the resultant focal length of two lenses is dependent on their spacing.

As a result of the high laser power, the optical elements in the beam path will heat, since they absorb a part, even though a slight part, of the laser energy. Preferably, the critical optical components are therefore not made of glass but of a material having better thermal conductivity, for example of sapphire. The waste heat, given metallization of the connecting surfaces of the optical components, is

eliminated by the solder connections to the mounts and to the housing. For better heat output, the housing is implemented with cooling ribs 92 that can be cooled by a ventilator (not shown). A permeation of the housing 35 as well as of the other component parts of the laser radiation source with bores is also possible, particularly in the critical regions at the lens mounts and mounts for the terminators 26, a coolant being capable of being pumped therethrough, as shown in Figs. 8 and 39.

Since, as presented above, extremely high laser powers are required in processing of materials, it is critical to the invention to keep the plurality of optical elements, particularly lenses, in the beam path as low as possible in order to keep the optical losses and the risk of contamination of the optics, which would always lead to a premature failure, as low as possible. It is also lies within the scope of the invention that the objective lens (61, 103 and 112) is equipped with an interchangeable mount so that it can be quickly replaced by the user of the laser radiation source as needed, whether because it has been contaminated during operation or because a different imaging scale is requested. In this case, it is advantageous that the bore 72 and the tube 54 is not implemented.

It also lies within the scope of the invention that techniques are undertaken in the optical beam path so that no laser energy can proceed back into the lasers. It is shown in Fig. 3 that the laser radiation impinges the material to be processed not perpendicularly but at an angle, so that the radiation reflected at the material surface cannot proceed back into the laser radiation source. It is also shown in Figs. 4, 4b, 4c and Fig. 18 that the laser radiation to be destroyed can be conducted by an obliquely placed concave lens 75 into a sump composed of an obliquely placed plate 86 that can be cooled. Instead of the concave lens of 75, some other optical component, for example a plate or a diaphragm, can also be inventively employed. The effective diameter of this optical component is thereby dimensioned such that the laser radiation conducted into the sump can just pass, whereas radiation that is reflected back from the sump or is dispersed back, is largely retained, so that no energy can proceed back into the laser. Inventively,

the surface of the plate 86, which is shown as a planar surface in the Figures, can also be implemented crowned or hollow and can be preferably roughened in order to absorb a maximum of radiation and reflect or, respectively, disperse a minimum of radiation.

It is also shown for two planes in Fig. 8 that, as a result of a slight parallel offset of the beam axes of the ray beams emerging from the terminator, an oblique incidence onto all effected lens surfaces can be achieved. This also applies for the arrangement having one or more planes. The acousto-optical modulator 34 is already rotated by the angle α_B relative to the axis of the ray beam; however, it can also be additionally rotated by the angle γ relative to the symmetry axis of the ray beam or an arrangement according to Fig. 24 can be employed wherein the axes of the ray beams emerging from the terminators proceed at an angle relative to one another. It has been shown in practice that angular differences of 1 through 2 degrees between the perpendicular onto the optical surface and the axis of the beam bundle are already adequate in order to achieve protection against radiation reflected back into the laser.

It lies within the scope of the invention to select embodiments of the optical, mechanical and electrical arrangement for Fig. 4 deviating from the described embodiment. For example, the radiation packets F_{D1} through F_{D4} and F_{R1} through F_{R4} could be focused onto the processing surface by a shared lens, similar to that shown in Fig. 31, which in fact yields a very high powered density but cannot present the shape of the processing spot as well since all processing points lie on one another and are united to form a common spot.

Fig. 4b shows another inventive laser gun for a laser radiation source that differs from the laser gun shown in Fig. 4 on the basis of a housing 93, terminators 94, a cylindrical tube 95, a tube 96 and on the basis of a highly reflective mirror 97.

The housing 93 has mounts 29 fitting the terminators 94. The terminators 94 preferably correspond to those of Figs. 10, 10a and 10b; the axes of the ray beams do not proceed parallel in the corresponding beam packets. Rather, they

proceed somewhat toward the center of the concave lens 101, which is shown in the plan view 21. However, all other terminators according to Figs. 5, 5a, 5b, 5c; 6, 6a; 7, 9, 9a; 11, 11a and 12 can also be employed when it is insured that the mounts 29 therefor are arranged at a corresponding angle. The transmission unit is located in the tube 96, this transmission unit being composed of three lenses, namely a dispersion lens, i.e. a concave lens 101, and two positive lenses, i.e. convex lenses 102 and 103, whereby the convex lens 103 is preferably implemented as an interchangeable objective lens. For the mounting of the lenses with respect to tightness and heat elimination, what was stated as to Fig. 4 and Fig. 4a applies, as it does for the selection of material with respect to the heat conduction.

The tube body 96 can be evacuated in the space between the lenses 101 and 102 or can be filled with a protective atmosphere or, preferably, be connected to the space 105 via a bore 104, said space 105 being in turn connected via a bore 106 to the space 107. The space 107 is connected to the space 111 via the bore 47, said space 111 being in turn terminated gas-tight, as described under Fig. 4 and Fig. 4a. The space between the lenses 102 and 103 can be connected via a bore (not shown) to the space 105, particularly when the mount of the objective is closed gas-tight or, as described under Fig. 4, when a slight amount of the protective atmosphere constantly flows through the laser gun and emerges in the proximity of the objective lens, this, however, not being shown in Fig. 4b. The entire interior of the laser gun, composed of the spaces 111, 105, 107, is preferably evacuated or filled with a protective atmosphere or, respectively, flooded by a protective atmosphere, as was described in detail under Fig. 4 and Fig. 4a. The undesired ray beams are intercepted with a highly reflective mirror 96; in contrast to Fig. 4, however, no lens system is present that has an angle-enlarging effect, so that the distance between the highly reflective mirror and the modulators is kept correspondingly large here in order to achieve an adequate spatial separation of the beam packets I_0 and I_1. Nonetheless, the entire structural length of the laser gun is similar here to the arrangement of Fig. 4. The optical

beam path of the transmission unit in Fig. 4 represents a side view. Fig. 21 indicates a fundamental beam path for a plan view relating to Fig. 4b. The beam path of the lenses 101 and 102 corresponds to that of an inverted Galileo telescope; however, it can also be implemented as an inverted Kepler telescope when the concave lens 101 having a short focal length is replaced by a convex lens. Such telescopes are described in the textbook "Optik" by Klein and Furtak, Springer 1988, pages 140 through 141. The advantage of the arrangement according to Fig. 4b is that only three lenses are required for the transmission unit. The disadvantage, to wit that the ray beams of the individual terminators do not proceed parallel, is eliminated by terminators according to Figs. 10, 10a and 10b.

A lens 55 could also be employed in order to deflect the ray bundles into the desired direction, as was shown in Fig. 20. The individual laser ray bundles would then proceed parallel to one another between the terminators 26 and the lens 55, that is arranged as in Fig. 4, and no difference from Fig. 4 derives with respect to the housing and the terminators or, respectively, their arrangement. Since, however, the lens 55 also exercises a collecting effect on the individual ray bundles in addition to the deflecting effect, the same conditions as in Fig. 21 would not arise at the location of the concave lens 101. This, however, can be compensated by a different adjustment of the spacing of the fiber 28 or, respectively, of the laser fiber 5 from the lens 133 or by a modification of the lens 133 in the terminators 26, i.e. the ray cone of the laser ray bundle from the individual terminators would be respectively set such that a sharp image respectively derives on the processing surface at the location of the points B_1 through B_n.

According to the invention, it is also possible to combine the lenses 102 and 103 to form a single, shared lens. A transmission unit having only two lenses then derives. It is also possible to arrange a displaceable lens (not shown) with a long focal length between the lenses 101 and 102, the focusing of the processing points on the processing surface being capable of being finely readjusted

therewith without displacing the radiation source. A vario-focusing optics can also be employed, as was mentioned under Fig. 4.

A special mouthpiece 82 is provided at the laser gun 23 that is intended to prevent a contamination of the objective lens 112 and that is described in greater detail under Fig. 34.

Fig. 4c shows a laser gun that is even more significantly compactly implemented than that of Fig. 4 and Fig. 4a. In combination with a mirror arrangement, an objective lens 112 is employed as transmission unit and this can be interchanged for achieving different imaging scales. As already described under Fig. 4, a vario-focusing optics can also be employed. Inventively, however, an imaging can occur with the mirror arrangement by itself without additional objective lens 112.

Fig. 4c differs form Fig. 4b in terms of the following points: The cylindrical tube 95 is replaced by an eccentric tube 113. The tube body 96 is preferably replaced by a plate 114 having a concave mirror 115 and a mount 116 with an objective lens 112 and a highly anti-bloomed plate 117. The intercept unit 73 is given an arced (convex) mirror 121 above the highly reflective mirror 97. The eccentric tube is connected to the housing 93 at one side. A seal 52 sees to the required tightness. The plate 114 is introduced into the eccentric tube 113, said plate 114 containing a passage for the beam packets I_0 and I_1 and carrying the concave mirror 115 whose dissipated heat can thus be diverted well to the eccentric tube. The eccentric tube has two axes that are preferably parallel to one another, namely, first the symmetry axis of the entering beam packets having the direction I_0 that are directed onto the arced mirror and, second, the axis between concave mirror and objective lens 112 that can be considered as an optical symmetry axis for the emerging laser radiation.

Inventively, the beam path is folded with the two mirrors 121 and 115. The arced mirror 121 is preferably fabricated of metal. It is intimately connected to the highly reflective mirror 97 and is preferably fabricated of one piece therewith. The convex surface of the arced mirror can be spherically or

aspherically shaped. The mirror 115 is concavely shaped, i.e. a concave mirror. Its surface can be spherically shaped but is preferably aspherically shaped. It is preferably composed of metal. Metal has the advantage of good elimination of the waste heat. A considerable advantage given manufacture of metal also derives in the production of aspherical surfaces, which, in this case, can be produced by known diamond polishing lathing methods, as can also spherical and planar surfaces. As a result thereof, the highly reflected mirror 97 and the arc mirror 121 can be manufactured of one piece and, preferably, in one work pass having the same shape of the surface and can be mirrored in common, which is particularly simple in terms of manufacture and very advantageous for the positional stability of the arced mirror. In the modulation of the laser energy with the acousto-optical modulator, it impinges either the arc mirror 121 or the highly reflective mirror 97. The waste heat that is produced remains the same in any case and the arced mirror stays at its temperature and, thus, its position, which is very important since it is preferably implemented with a short focal length and the imaging quality of the arrangement is therefore very dependent on its exact position. In this case, the arced mirror 121 has advantageously co-assumed the function of the highly reflected mirror 97. The highly reflective mirror 97 can, however, also have some other form of surface than the arced mirror 121 and, for example, can be a plane mirror.

The beam path is similar to that of an inverted mirror telescope of Herschel that, however, contains a convex lens instead of the arced mirror and that is described in greater detail in Fig. 22. Mirror telescopes are described on page 152 in the "Lehrbuch der Experimentalphysik Band III, Optik" by Bergmann-Schäfer, 7th edition De Gruyter 1978. The arced mirror can also be replaced by a concave mirror having a short focal length. As a result thereof, the structural length would be slightly enlarged and different ray cones of the ray bundles emerging from the terminator would have to be set in order to obtain a sharp image in the image plane. The arced mirror could also be replaced by a convex lens having a short focal length. Another folded mirror would then have

to be utilized in order to preserve the compact structure. The intercept arrangements 73 is attached gas-tight to the eccentric tube via a seal 76 the undesired laser energy, as described under Figs. 4, 4b and 18, being diverted via said intercept arrangement 73 to a cooling plate 86 with bores 87 and being neutralized. It is also possible to already intercept the undesired laser radiation from the beam packet I_1 at the location of plate 114 and neutralize it.

The space 111 in the housing 93 is connected to the cavity 123 via the bore 122. Both spaces can be evacuated, filled with a protective atmosphere, or flooded by a protective atmosphere, as already described. The mount 116 that accepts the interchangeable objective lens 112 is attached to the end of the eccentric tube 113 that resides opposite the housing 93. A seal 124 closes the cavity 123 gas-tight. The mount can also accept an anti-bloomed plate 117 whose edge is preferably metallized and that is preferably soldered gas-tight to the mount. Its job is to keep the cavity 123 gas-tight when the objective lens was removed for cleaning or when an objective lens having a different focal length is to be introduced in order to generate a different imaging scale. The space between the objective lens 112 and the highly anti-bloomed plate 117 can also be connected to the space 123 via bore (not shown), particularly when the entire laser gun, as described under Fig. 4, constantly has a protective atmosphere flowing through it, this emerging in the proximity of the objective lens 112, which is shown in Fig. 39a. The highly anti-bloomed plate 117, however, can also contain optical correction functions, as known for the Schmidt optics known from the literature, in order to thus improve the optical imaging quality of the arrangement. However, it is also possible to omit the highly anti-bloomed plate, particularly when it contains no optical correction function and the objective lens was introduced gas-tight or a protective atmosphere flowing therethrough sees to it that no dirt can enter into the space 123 when the objective lens is replaced. A special mouthpiece 82 is provided at the laser gun 23, this being intended to prevent a contamination of the objective lens 112 and being described in greater detail under Fig. 34.

The eccentric tube can be provided with cooling ribs 92 over which a ventilator (not shown) can blow in order to eliminate the waste heat to the environment better. The laser gun is rotatably seated in a prism around the axis between concave mirror and objective lens in order, as described under Fig. 4, to make the track spacing adjustable and in order to set the correct distance from the processing surface 81. The laser gun can be fixed with a strap retainer 85.

It is possible to arrange a displaceable lens (not shown) having a long focal length between, preferably, the concave mirror 115 and the objective lens 112, the focusing of the processing points onto the processing surface being capable of being finely readjusted therewith without displacing the laser gun. However, a variable focusing optics can also be utilized, as was described under Fig. 4. All descriptions that were provided for Figs. 4, 4a and 4b also apply analogously.

Fig. 5 shows a preferred embodiment of a terminator 26 for a fiber 28 or laser fiber 5, which is also a fiber. Plug-type connections for optical fibers for low powers are known in optical communications technology, in sensor applications and measurement technology; these, however, are not suitable for high powers because too much heating occurs, this leading to destruction. For example, such laser diode collimator systems, beam shaping optics and coupling optics are described in the catalog 1/97 of Schäfter & Kirchhoff, Celsiusweg 15, 22761 Hamburg, pages A1 through A6. However, the power of these systems is limited to 1000 mW and is thus below the demands for the desired applications in processing materials by a factor of 100 because an adequate heat elimination is not assured. Further, these systems are relatively large in diameter, so that no high packing density of the laser outputs can be achieved. Another great disadvantage is that these systems are not adequately sealed; they would get dirty very quickly and burn up due to an increased absorption of the laser radiation. Last but not least, it should also be mentioned that the precision of the mount for fibers and the lens are inadequate for the desired application. Terminators according to this patent application are therefore significantly more advantageous.

Such terminators can be advantageously employed for coupling laser radiation out of a fiber 5, 28, as disclosed in the German Patent Application P 198 40 935.4 of the assignee "Abschlussstück für Lichtleitfasern".

This terminator 26 can be fundamentally used for all applications wherein the matter of concern is that the ray bundle emerging from a fiber 5, 28 be precisely coupled with a releasable connection. It is likewise possible with the assistance of this terminator to produce a precise, releasable connection of the fiber 5, 28 to the remaining optics. The terminator is composed of an oblong housing 132 that comprises a through cylindrical opening 130 extending in axial direction. The housing is preferably manufactured of prefabricated, for example drawn material that can preferably be composed of glass. The laser fiber 5 of the fiber laser is preferably stripped of its cladding at its ultimate end and is preferably roughened at its outside surface, this being disclosed in German Patent Application P 197 23 267, so that the remaining pump radiation leaves the laser fiber before the entry of the laser fiber into the terminator. The fiber 5, 28 can also be additionally surrounded by a single-layer or multi-layer protective sheath 131 that can be connected to the housing 132 of the terminator, for example with a glued connection 142. The housing 132 comprises fits 134 with which the housing can be exactly introduced in a mount 29 (Fig. 5a, Fig. 7, Fig. 8, Fig. 14). The fits can thereby extend over the entire length of the housing (Figs. 5b, 9, 10); however, it can also be attached in limited regions of the housing (Figs. 5, 6, 7). One or more seals 36 can be provided that, for example, are connected to the housing 132 with glue connections 142. The job of the seals is to enable a gas-tight connection of the terminators to the mounts 29. The housing can have a different diameter, for example a smaller diameter, in the region of the protective cladding 131 and of the seal 36 than in the region of the fits. At the end of the housing 132, the end of the fiber 28 or, respectively, of the laser fiber 5 is accepted and conducted within the housing in the opening 130. A lens 133 having a short focal length is secured to the other end of the housing 132, whereby the housing can comprises a conical expansion 139 so as not to impeded the laser

radiation 13. Means can be provided for adjusting the position of the fiber 5, 28 within the terminator in order to adjust the position of the fiber relative to the lens 133 within the terminator and with reference to the fits 134, as shown in Figs. 5b, 5c, 6, 6a, 7, 9, 9a, 10a, 10b, 11, 11a and 12. The radial position of the fiber 5, 28 can also be defined by the cylindrical opening 130, whereby the fiber is axially displaceable within the opening. The position of the lens 133 can either be adequately precisely mounted during assembly or can be axially and/or radially adjusted and fixed with suitable means (not shown) with reference to the fiber 5, 28 and to the fits 134, whereby the fiber can also be axially displaced (Fig. 5b). The adjustments are advantageously undertaken with a measuring and adjustment device. What the adjustment is intended to achieve is that the ray bundle 144 emerging from the lens 133 is brought into a predetermined axial and focus position with a defined cone relative to the fits 134. After a fixing of the fiber 5, 28 within the housing 132 and of the lens 133 at the housing, the measuring and adjustment device is removed. Inventively, it is also possible to provide the end of the fiber 5, 28 with a suitable coating, for example a correspondingly thickly applied metallization 141, in the region of the terminator before assembly in order to further improve the durability of the adjustment. The fixing of the fiber 5, 28 within the housing 132 can occur with suitable means such as gluing, soldering or welding. An elastic compound 138 that represents an additional protection for the fiber is preferably provided at the transition between the housing 132 and the protective sheath 131. It is also inventively possible to fashion and align the lens 133 by corresponding shaping and vapor-deposition of a corresponding layer, preferably at its side facing toward the fiber end, such that it co-assumes the function of the outfeed mirror 12 for the fiber laser.

Fig. 5a shows a multiple arrangement of fiber laser outputs with the terminators from Fig. 5. Bores 150 for the acceptance of two terminators 26 for two tracks are provided in a housing 145. Further, respectively three pins 148 and 149 are attached in rows such within the housing 145 in extension of the bores that they represent a lateral limitation as mount 29 for the terminators and see to a

precise guidance and alignment of the terminators. The diameters of the pins 148 are referenced d_1 and are preferably identical to one another. The diameters of the pins 149 are referenced d_2 and are preferably likewise identical to one another. If the diameters of the pins 148 were the same as the diameters of the pins 149, the axes of the ray beams of both tracks would lie parallel to one another in the plane of the drawing since the terminators 26 comprise cylindrical fits 134. In Fig. 5a, however, the diameters of the pins 149 are shown larger than the diameters of the pins 148, this resulting in the axes of the two ray beams proceeding at an angle relative to one another in the plane of the drawing. The angle between the ray beams is dependent on the diameter difference d_2 - d_1 and on the center-to-center spacing m of the two pin rows. The terminators are conducted through the housing 145 at the underside in one plane and are conducted from above through a cover (not shown) of the housing that is secured to the housing and can close it gas-tight with a seal (not shown). The housing 145 can be part of a receptacle for an optical unit for shaping the laser radiation. The terminators are secured to the housing 145 with clips 147 and screws (not shown), whereby the seals 36 see to a gas-tight closure. The arrangement is not limited to two tracks; further bores 150 can be provided and further pins 148 and 149 can be introduced in order to insert further terminators for further tracks. The arrangement is not limited to the one plane as described; further bores 150 can be inserted into the housing 145 in further tracks and in one or more further planes, these lying above or below the plane of the drawing, and the pins 148 and 149 are lengthened to such an extent that they represent mounts 29 for all tracks and all planes. Inventively, pins 148 and 149 are likewise employed for producing a defined spacing between the planes. In this case, the pins proceed horizontally between the terminators. For example, the horizontally arranged pins 149 proceed between the wall of the housing 145 wherein the bores 150 lie and the row of illustrated, vertically arranged pins 149. The horizontally arranged pins 148 preferably proceed at a spacing m parallel to the horizontally arranged pins 149. Horizontally arranged pins are not shown in Fig. 2a. The pins 148, 149 are preferably fabricated of

drawn steel wire; however, they can also be composed of other materials, for example of drawn glass. An advantage given the arrangement with a plurality of tracks and/or planes in the illustrated way is that the pins 148, 149 exhibit a certain flexibility. As a result thereof, it is possible to press the entire packet of the terminators together in the direction of the tracks and in the direction of the planes such that the terminators 26 with their fittings 134 lie against the pins without spacing, this being desirable for achieving utmost precision.

Fig. 5b shows a terminator 26, whereby means for adjusting the position of the fiber 5, 28 within the terminator are provided in order to be able to adjust the position of the fiber 5, 28 relative to the lens 133 within the terminator and with respect to the fittings 134. The position of the lens can also be adjusted. The adjustments are advantageously undertaken with an adjustment device. Adjustment screws 135, 136 (Figs. 5b, 5c, 9, 9a, 10a, 10b, 11, 11a, 12) and/or balls 137 (Figs. 6, 6a, 7) can be provided for the adjustment of the position of the fiber 5, 28 in the housing 132. The fiber 28 or laser fiber 5 can also be axially displaced within the adjustment screws 135, 136 or balls 137. The position of the lens 133 can either be adequately precisely mounted during assembly or axially and/or radially adjusted and fixed by means (not shown) with reference to the fiber 5, 28 and with reference to the fittings 134, whereby the fiber can also be axially displaced. The adjustments are advantageously undertaken with a measuring and adjustment device. What the adjustment is intended to achieve is that the ray bundle 144 emerging from the lens 133 is brought into a predetermined axial and focus position with a defined cone on the basis of a relative advance of lens 133 and fiber 5, 28 toward the fits 134. After a fixing of the fiber 5, 28 within the housing 132 and of the lens 133 to the housing, the measuring and adjustment device is removed. That stated under Fig. 5 for this and the other embodiments continues to apply, for example regarding the metallization 141, the elastic compound 138 and the employment of the lens 133 as laser mirror.

Fig. 5c shows a cross-section through the terminator 26 in the region of the adjustment screws, from which it can be seen that preferably three adjustment screws 135 are provided distributed over the circumference, the fiber 28 or, respectively, the laser fiber 5 being adjustable in fine fashion in the housing therewith. Further, further adjustment screws 136, as shown in Fig. 5b, can be provided within the terminator at the end of the terminator at which the fiber 28 or, respectively, the laser fiber 5 enters. These adjustment screws are designed like the adjustment screws 135. When only one set of adjustment screws 135 is employed, the fiber 28 or the laser fiber 5 can only be adjusted with respect to the angle. When two sets of adjustment screws are employed, they can also be displaced parallel to their axis. The fixing of the fiber 5, 28 within the housing 132 can occur with suitable means such as gluing, soldering or welding.

Fig. 6 shows an embodiment of the terminator 26 wherein small balls 137 of metal or, preferably, metallized glass are employed instead of adjustment screws, these being brought into their position in the housing and being subsequently glued or soldered. A plurality of sets of balls can also be applied.

Fig. 6a shows a cross-section through the terminator in the region of the balls 137.

In order to prevent the optical surfaces on the optical fiber and the side of the lens 133 that faces toward the optical fiber from contaminating biparticles in the ambient air, the connections in Figs. 5, 5b, 5c, 6, 6a, 7, 9, 10, 11, 11a and 12 between the lens 133 and the housing 132 as well as between the adjustment screws 135 and 136 or, respectively, the balls 37 and the housing 132 can be hermetically closed. This can occur with suitable glued or soldered connections 142. When a soldered connection is preferred, the glass parts are previously metallized at the corresponding locations 141. In order to achieve a greater strength, the glued or soldered connections can also entirely or partially fill the remaining gap between the fiber 28, the laser fiber 5 and the housing 132, or the protective sheath 131 in the proximity of the terminator, this being shown, by way

of example, in Fig. 5. It is also possible to durably evacuate the interior 143 of the housing or fill it with a protective atmosphere.

Fig. 7 shows a further embodiment of a terminator 26 that is introduced in a housing 145 with a mount 29. Given this embodiment, the front, outer fitting 134 in the region of the lens 133 is conically implemented for better sealing and for better heat elimination. Additionally, a seal 146 can be provided that instead of being attached to the lens-side end of the terminator as shown, can also be attached to the fiber-side end thereof.

Fig. 8 shows mounts 29 in a housing 145 for a plurality of conically implemented terminators 26 according to Fig. 7. Such mounts are advantageous when a plurality of outputs of fibers or fiber lasers are to be arranged next to one another or next to one another and above one another. The axes of the mounts can thereby be arranged such that the axes of the ray beams emerging from the terminators of the terminators lying side-by-side and/or above one another proceed parallel to one another or at an angle. In order to eliminate the waste heat, the housing 145 can be inventively provided with bores through which a coolant is conducted.

Fig. 8a shows the rear fastening of the terminators 26 in the housing 145. For fixing the terminators 26, 94, clips 147 are provided that fix the ends of the terminators with screws 151 in the housing at the locations at which the fibers respectively enter into the housing of the terminators 26, 94.

Fig. 9 shows an embodiment of a terminator 26 having a quadratic or rectangular cross-section, whereby all outside surfaces lie opposite one another proceed parallel and can be fittings 134. Fig. 9a shows a cross-section through the terminator 26 according to Fig. 9 having a quadratic cross-section.

Fig. 10 shows an embodiment of the terminator 94 with rectangular cross-section, whereby two outside surfaces lying opposite one another proceed trapezoidally and two outside surfaces lying opposite one another proceed parallel to one another. The outside surfaces can be fittings 134.

Fig. 10a shows a longitudinal section and Fig. 10b a cross-section through the terminator according to Fig. 10.

Fig. 11 shows terminators 26 having trapezoidal cross-sections, so that a row of terminators arises by successive turning of the terminators by 180° when a plurality of terminators are joined to one another, whereby the center points of the terminators lie on a central line. When desired, a plurality of such rows can be arranged above one another, which is indicated with broken lines in Fig. 11.

Fig. 11a shows terminators 26 with a triangular cross-section that can likewise be arranged in a plurality of rows above one another, this being indicated with broken lines.

Fig. 12 shows terminators 26 having a hexagonal cross-section that can be arranged honeycomb-like for increasing the packing density.

The inventive terminators advantageously enable the laser radiation source to be built of individual modules.

Fig. 13 shows an applied example of the terminator 26 or 94 given a fiber 28 or a laser fiber 5 that have both ends provided with a respective, inventive terminator.

According to the invention, it is possible to preferably implement the lens 133 at its side facing toward the fiber end on the basis of a corresponding shape being and vapor-deposition of a corresponding layer such that it co-assumes the function of the outfeed mirror 12. According to the invention, it is also possible to implement the lens 3, 154 by corresponding shaping and vapor-deposition of a corresponding layer that it co-assumes the function of the infeed mirror 7.

It is fundamentally possible to combine a plurality of the terminators described above in a plurality of tracks side-by-side and above one another in a plurality of planes to form a packet.

It is also possible to implement the shape of the terminators differently from that shown in the Figures, for example that a cylindrical shape according to Fig. 6 is lent trapezoidal or rectangular fits according to Fig. 9 or Fig. 10.

Fig. 14 shows a coupling of the laser fiber 5 to a pump source with the terminator 26 via the housing 152 in which the pump source 18 is accommodated in a recess 153, preferably gas-tight. A seal 146 assures that the terminal 26 likewise terminates gas-tight, so that no dirt particles can penetrate into the recess from the outside and, as needed, it can be evacuated or filled with a protective atmosphere. A constant current of a protective atmosphere can also flow through the recess 153, particularly given temporary removal of the terminator 26. The radiation of the pump source 18 is focused onto the pump cross-section of the laser fiber 5 via a lens 154. The pump source can be composed of one or more laser diodes; however, it can also be composed of an arrangement of one or more lasers, particularly fiber lasers as well, whose output radiation was united such with suitable means that a suitable pump spot arises.

Fig. 15 shows the branching of the output radiation from the laser fiber 5 of a fiber laser with a fused fiber coupler 155. Such fused fiber couplers are described for single-mode fibers on Page G16 of the catalog of Spindler and Hoyer specified in greater detail under Fig. 20 and can be directly fused to the output of the laser fiber 5 after correspondingly precise alignment. In this case, thus, the terminator 26, 94 is connected to a passive single-mode fiber or, respectively, to a different fiber 28 and not directly to a fiber laser with the active laser fiber 5. There are also other possibilities of splitting the laser beam into a plurality of sub-beams such as, for example, beam splitter mirrors or holographic beam splitters. The advantage of the described fused fiber coupler, however, is that the laser radiation can be brought to the processing point guided within fibers insofar as possible, this leading to a considerable simplification of the arrangement.

Fig. 16 shows the uniting of the radiation from the laser fibers 5 of two fiber lasers via a fused fiber coupler 156. The cross-sections of the two input fibers are united to form one fiber in the fused fiber coupler 156. For example, the diameter of the fibers at the two inputs of the fused fiber coupler amounts to 6 µm and the core diameter of the two laser fibers to be fused on likewise amounts

to 6 μm. A core diameter of the single-mode fiber at the output of the fused fiber coupler thus becomes 9 μm, which still allows a faultless guidance of a single mode for the corresponding wavelength. The diameter at the output of the fused fiber coupler, however, can also be greater than 9 μm, and more than two outputs of fiber lasers or, respectively, fibers can be united. The terminator 26, 94 in this case is thus connected to a passive single-mode fiber or other passive fiber 28 and not to a fiber laser with the active laser fiber 5.

However, all other types of light waveguides can be welded to the fiber laser or coupled thereto in some other way, for example via optics.

One or more passive single-mode fibers or one or more other passive fibers 28 can also be coupled to an individual fiber laser instead of a brancher according to Fig. 15 or a combiner according to Fig. 16, being coupled via optics in order to then connect the terminator to this single-mode fiber or other fiber.

However, it is also possible to unite the outputs of a plurality of fiber lasers or single-mode fibers or other suitable fibers into which laser radiation can be coupled via wavelength-dependent or polarized beam combiners or other suitable techniques, and to in turn couple into single-mode fibers or other fibers that can be provided with a respective, corresponding terminator at one or both ends.

The described possibilities of branching and uniting fibers can be particularly advantageously employed when the inventive modular structure is applied to the laser radiation source.

Fig. 17 shows the principle of an acousto-optical deflector. A piezo-electric transducer 45 is applied on a substrate 161 that is also referred to as crystal, said piezo-electric transducer 45 being supplied with electrical energy from a high-frequency source 162. The laser beam 163 incident at a Bragg angle α_B is deflected out of its direction proportionably to the frequency of the high-frequency source by interaction with the ultrasound field 164 within the crystal. When the beam that is not deflected and that passes through the modulator at the moment is referenced I_0 (beam of the zero order), then the frequency f_1 yields a

direction I_{11} (first beam of the first order), and the frequency f_2 yields a direction I_{12} (second beam of the first order). Both frequencies can also be simultaneously present and the beams I_{11} and I_{12} arise simultaneously, these being capable of being modulated by varying the amplitudes of the high-frequency sources. An optimum transmission efficiency for the infed radiation respectively derives when the Bragg angle amounts to half the angle between the direction of the ray beam I_0 and the direction of the deflected ray beam. For use as acousto-optical modulator, only one of the sub-beams is used. It is mostly effective for processing materials to employ the beam of the zero order because it has the higher power. However, it is also possible to use one or more beams of the first order. The energy of the beams that is not used is neutralized in that, for example, it is converted into heat on a cooling surface. Only one piezo-electric transducer 45 is provided in Fig. 17, for which reason only one laser beam 163 can be deflected or modulated. However, a plurality of piezo-electric transducers can also be attached on the same substrate in order to thus simultaneously provide a plurality of laser beams, i.e. a plurality of channels, with different deflection or modulation signals. The individual channels are referenced T_1 through T_n. When, as shown in Fig. 17, the acousto-optical modulator is placed into a focal point of the lens 165 and the beam path is implemented nearly parallel through the acousto-optical modulator, the beams in the other focal point of the lens 165 are focused on the processing surface arranged here, and the beam axes between the lens 165 and the processing surface 81 proceed parallel and impinge the processing surface perpendicularly. Such an arrangement is called telocentric; the advantage is that the spacing between the beam axes remains constant when the position of the processing surface changes. This is of great significance for a precise processing of material.

Fig. 18 shows how the unused beam is neutralized. The unused beam is intercepted and deflected via a highly reflective mirror 166, which is preferably manufactured of metal for better heat elimination, is dispersed by a concave lens 75 and is directed onto an obliquely arranged plate 86 having bores 87 such that no energy can be reflected back into the laser. The plate 86 and, potentially, the

mirror 166 are also cooled via a cooling system that is operated by a pump 167. It is also possible to utilize a convex lens of a glass plate instead of the concave lens. The convex lens, particularly when a dispersion of the ray beam to be neutralized can be undertaken with other techniques, which can occur, for example, by special shaping of the highly reflective mirror 166, is described under Fig. 4c. The concave lens 75 can also be omitted when one foregoes the advantage of the complete sealing of the laser gun. The plate 86 is shown with a planar surface at an angle. A plate having an arc or a cavity can also be employed. The surface can be roughened in order to absorb the laser energy well which is conducted to the coolant.

It is advantageous for an arrangement having a plurality of tracks to arrange a plurality of such modulators on a common crystal 34 according to Figs. 19 and 19a. The individual modulators cannot be arranged arbitrarily close to one another because of too much heating. A modulator of Crystal Technology Incorporated, Palo Alto, USA, is especially suited for the inventive arrangement, this being distributed under the designation MC 80 and containing five separate deflection or modulator channels. In this case, the spacing of the channels is predetermined at 2.5 mm, whereby the beam diameter is recited as 0.6 mm through 0.8 mm. A similar product by the same company is equipped with ten channels having a spacing of 2.5 mm. The spacing of the channels of 2.5 mm requires the diameter or the edge length of the terminators 26, 94 is implemented smaller than 2.5 mm. When the terminator 26, 94, however, is greater in diameter or in edge length than the spacing of the channels in acousto-optical deflector or modulator, an adaptation can be undertaken with an intermediate imaging, as shown in Fig. 25. Such a multi-channel deflector or modulator can also be employed in the exemplary embodiments according to Figs. 4, 4a, 4b, 4c, 36, 36a and 37. Dependent on the requirement of the application, all channels need not be used. Only four channels are shown in the illustrated applied examples.

Instead of the acousto-optical modulator, however, it is also possible to utilize other modulators, for example what are referred to as electro-optical

modulators. Electro-optical modulators are described under the terms "laser modulators", "phase modulators" and "Pockels cells" on pages F16 through F33 of the overall catalog G3, Order No. 650020 of Laser Spindler & Hoyer, Göttingen. Multi-channel electro-optical modulators have also been possibly employed, which is shown in the publication "Der Laser in der Druckindustries" by Werner Hülsbuch, Verlag W. Hülsbusch, Constance, page 523, Fig. 8-90a. When a one-channel or multi-channel electro-optical modulator is employed in combination with a birefringent material, then each laser beam can be split into two beams that can be separately modulated via further modulators. Such an arrangement is also referred to as an electro-optical deflector in the literature.

Fig. 18a shows an arrangement having an electro-optical modulator 168. In an electro-optical modulator, for example, the polarization direction of the laser radiation that is not wanted for processing is separated from the incident ray beam 163, and turned (P_b), and subsequently, the laser radiation P_b not wanted for the processing is separated off in a polarization-dependent beam splitter, which is also referred to as polarization-dependent mirror 169, and is conducted into a sump, for example into a heat exchanger that can be composed of a cooled plate 86. The radiation P_a wanted for processing is not turned in terms of polarization direction and is supplied to the processing surface via the lens 165. In the exemplary embodiments according to Figs. 4, 4b and 4c, the single-channel or multi-channel acousto-optical modulators 34 can be replaced by corresponding, single-channel or multi-channel electro-optical modulators. In the exemplary embodiments according to Figs. 4, 4b and 4c, the highly reflective mirror 74, 97 can likewise be replaced by the polarization-dependent mirror 169 (Fig. 18a), wherefrom an intercept arrangement 78 derives, and whereby the polarization-dependent mirror extends into the beam path desired for the processing.

The fiber laser can also be directly modulated. Such directly modulatable fiber lasers that have a separate modulation input available to them are offered, for example, by IPG Laser GmbH D-57299 Burbach, under the designation "Modell YPLM Series". The advantage is that the acousto-optical modulators

and the corresponding electronics for the high-frequency sources can be omitted. Moreover, the transmission unit can be simplified, as shown in Fig. 23.

Fig. 19 shows a plan view onto an acousto-optical deflector or modulator. It is mentioned in the description of Figs. 4, 4b and 4c that the space 44 or 111 according to Figs. 4, 4b and 4c wherein the modulators are arranged should be optimally free of those components that give off particles or gases because particles could thus settle onto the highly stressed optical surfaces, which would lead to the premature failure of the arrangement. For this reason, the electrical components of the arrangement in Figs. 19 and 19a are arranged on a separate printed circuit board 171 that merely has two arms projecting into the sealed space and produces the electrical connections to the piezo-electrical sensors 45. The printed circuit board 171 is sealed relative to the modulator housing 172, preferably with a solder location 173. The end face of the printed circuit board is preferably sealed by a metal band (not shown) that is soldered on in the region of the space 44 or 111. The printed circuit board is implemented in multi-layer fashion in order to shield the individual high-frequency channels by interposed connections to ground. Instead of a printed circuit board, some other line arrangement can also be utilized. For example, each radio frequency channel can be connected by its own shielded line. The modulator housing 172 contains an access opening 174 to the electrical components. The modulator crystal 34 can be metallized at its base area and is preferably secured on the modulator housing with a solder point or a glued connection 175. A connection 176 to a cooling system can be located directly under the fastening location in order to carry the waste heat off via the openings 87 with a coolant. The modulator housing 172 is preferably closed by a cover 177 that carries the electrical terminals 181 and also contains the connections for the cooling system, but this is not shown. A seal 43 sees to it that the modulator housing 172 is inserted gas-tight into the housing 35 or 93 of Figs. 4, 4a, 4b and 4c and is secured with the connection 42.

It is possible to secure the electro-optical modulator 168 to the modulator housing (172) in a similar way and to contact it via the printed circuit board 171.

Fig. 20 indicates that the basic beam path for the exemplary embodiment of Fig. 4 for the ray beams 144 of the corresponding fiber lasers F_{HD1} through F_{HD4}. The ray beams of the fiber lasers F_{VD1} through F_{VD4} proceed partially congruently with the indicated rays but, inventively, have a different wavelength and, as can be seen from Fig. 4a, are united via a wavelength-dependent mirror 37 (not shown in Fig. 20) with the beam packet F_{HD1} through F_{HD4} to form the beam packet F_{D1} through F_{D4}. Further, Fig. 20 does not show the beam packets of the fiber lasers F_{VR1} through F_{VR4} and F_{HR1} through F_{HR4} that, as can be seen from Fig. 4a, are likewise combined via a wavelength-dependent mirror to form the beam packet F_{R1} through F_{R4}. As can be seen from the arrangement of the strip mirror 46 in Fig. 4a, the ray beams of the beam packet F_{R1} through F_{R4} in Fig. 20 would proceed offset by half a track spacing from the indicated rays. Instead of containing the indicated four ray beams, thus the complete beam path contains a total of eight ray beams that yield a total of eight separate tracks on the processing surface. Fig. 20 only shows the two ray beams 144 of the fiber lasers F F_{HD1} and F_{HD4}. As already mentioned under Fig. 4, however, a plurality of tracks can also be arranged; for example, the plurality of tracks on the processing surface can also be increased to sixteen separately modulatable tracks. On the basis of a digital modulation of the respective laser, i.e. the laser is operated in only two conditions as a result of turn-on and turn-off, this arrangement enables an especially simple control and a good shaping of the processing spot on the processing surface. This digital type of modulation requires only one especially simple modulation system.

A distinction between more than 100 tonal value levels is required in high-grade multi-color printing in order to obtain adequately smooth color progressions; more than 400 tonal value stages would be optimum. When, for example, a cup in rotogravure wherein the volume of the cups determines the amount of ink applied onto the material being printed is composed of 8 x 8 or 16 x 16 small individual cups and the cup depth is kept constant, the processed surface can be quantitized into 64 or 256 stages. When, however, the cup depth is controlled by additional, analog or digital amplitude modulation or by a pulse-

duration modulation of the laser energy, the volume of the cups can be arbitrarily finely quantized even given a low plurality of tracks. If, for example, the cup depth were digitally controlled in only two stages, as described in greater detail under Fig. 28, a cup could be composed of 8 x 8 individual cups given eight tracks, these potentially having respectively two different depths. For example, the volume of the cups in this case could be quantized in 128 stages without losing the advantage of purely digital modulation, which yields a considerable advantage for the stability of the method. Given 16 tracks and 2 stages in the cup depth, the number of digitally possible quantization stages already amounts to 512. It is also possible to generate the cups in two processing passes in order to increase the number of tonal value steps.

The modulators 34 as well as the strip mirror 46 are not shown in Fig. 20. For a better illustration, the cross-section of the ray beam 144 from the terminator of the fiber laser F_{HD1} that is congruent with the ray beam F_{D1} after passing the wavelength-dependent mirror is designed with a hatching. Like all other illustrations, this illustration is not to scale. The two illustrated ray beams 144 yield the processing points B_1 and B_4 on the processing surface 81 that contribute to the built-up of the processing spot 24 and generate corresponding processing tracks on the processing surface 81. The axes of the terminators 26 and of the ray beams 144 of the individual fiber lasers proceed parallel to one another in Fig. 20. The beam cones of the terminators, i.e. the shape of the ray beam 144, are shown slightly divergent. In the Figure, a beam narrowing within the lens 133 is assumed in the Figure. The divergence angle is inversely proportional to the diameter of the ray bundle in the corresponding beam narrowing. The position of the beam narrowing and its diameter, however, can be influenced by varying the lens 133 in the terminator 26, 94 and/or its distance from the fiber 28 or from the laser fiber 5. The calculation of the beam path occurs in the known way. See the technical explanations on pages K16 and K17 of the general catalog G3, Order No. 650020 of Laser Spindler & Hoyer, Göttingen. The objective is that the processing points B_1 through B_n of the processing surface 81 respectively become

beam narrowings in order to obtain the highest power density in the processing points. With the assistance of the two lenses 55 and 56, beam narrowings and track spacings from the object plane 182 wherein the lenses 133 of the terminators 26 lie are imaged in demagnified fashion in an intermediate image plane 183 corresponding to the ratio of the focal lengths of the lenses 55 and 56. When, in this case, the distance of the lens 55 from the terminator 26 and from the crossing point 184 is equal to its focal length and when the distance of the lens 56 from the intermediate image plane 183 is equal to its focal length and equal to its spacing from the crossing point 184, what is referred to as a telecentric imaging is obtained, i.e. the axes of the ray bundles belonging to the individual tracks begin to proceed parallel in the intermediate image plane. The divergence, however, has been noticeably increased. The preferably telecentric imaging has the advantage that the diameters of the following lenses 57 and 61 need only be insignificantly larger than the diameter of a ray bundle. The lenses 57 and 61 demagnify the image from the intermediate image plane 183 in a second stage onto the processing surface 81 in the described way. A preferably telecentric imaging, namely that the axes of the individual ray beams proceed parallel between the objective lens 61 and the processing surface 81, has the advantage here that changes in spacing between the processing surface and the laser gun produce no change in the track spacing, which is very important for a precise processing. The imaging need not necessarily occur in two stages with two lenses each; there are other arrangements that can also generate parallel beam axes between objective lens and processing surface, as shown in Figures 21 and 22. Deviations in the parallelism of the beam axes between the objective lens 61 and the processing surface 81 can also be tolerated as long as the result of the processing of the material is satisfactory.

Fig. 21 shows a fundamental beam path for the exemplary embodiment of Fig. 4b. The illustration is not to scale. As was already the case in Fig. 20, the two ray bundles 144 of the lasers F_{HD1} and F_{HD4} are only a matter of a sub-set of the ray bundles of all existing lasers in order to explain the principle. In contrast

to Fig. 20, however, the axes of the individual ray bundles of the terminators in Fig. 21 are not parallel but are arranged at an angle relative to one another, which is shown in greater detail in Fig. 24, and which is advantageously achieved by terminators 94 according to Figs. 10, 10a and 10b. As a result of this arrangement, the individual ray bundles 144 would cross similar to the case in Fig. 20 without a lens 55 being required. In the region of the imaginary crossing point, the dispersive lens with a short focal length, i.e. a concave lens 101 is inserted, this bending of the incoming rays off and rendering of the ray bundles divergent is shown, i.e. widening them. The convex lens 102 is preferably arranged in the intersection of the axial rays and, together with the lens 101, forms an inverted Galileo telescope. As a result thereof, for example, parallel input ray bundles are converted into parallel output ray bundles having an enlarged diameter between the lenses 102 and 103. The desired parallelism of each input ray bundle can, as already described, be undertaken by a suitable selection of focal length and spacing of the lens 133 from the fiber 28 or laser fiber 5 in the terminators 26, 94. The objective lens 103 focuses the enlarged ray bundle onto the processing surface 81 at the processing points B_1 through B_4 that contribute to the built-up of the processing spot 24 and generate corresponding processing tracks on the processing surface 81. The imaging scale can be modified in a simple way by modifying the focal length of the lens 103. It is therefore advantageous when the lens 103 is implemented as an interchangeable objective lens. As already described, however, a vario-focusing optics can also be employed. When the position of the lens 103 is selected such that the distance between the lenses 102 and 103 corresponds to the focal length of the lens 103, the axes of the ray bundles between the lens 103 and the processing surface are parallel and yield constant spacings of the tracks of the processing surface, even given a modified between the laser gun and the processing surface.

Fig. 22 indicates the fundamental beam path for the exemplary embodiment of Fig. 4c. Like all other figures, the illustration is not to scale. The beam path is very similar to that of Fig. 21, with the difference that an arced

mirror 121 is employed instead of the lens 101 and a concave mirror 115 is employed instead of the lens 102. The beam path is considerably shorter due to the folding that derives. The beam path approximately corresponds to that of an inverted mirror telescope. Mirror telescopes are independent of the wavelength which is advantageous given employment of lasers having different wavelength. The imaging errors can be reduced by employing aspherical surfaces or with an optical correction plate 117 that, however, is not shown in Fig. 22. It is advantageous from the focal length of the objective lens 112 is equal to its spacing from the concave mirror. The axes of the ray bundles are then parallel between the lens 112 and the processing surface 81 and yield constant spacings of the tracks on the processing surface, even given a modified distance between the laser gun and the processing surface. Moreover, an advantageously large spacing of the objective lens from the processing surface derives. As described a vario-focusing optics can also be utilized.

Fig. 23 shows an arrangement having a plurality of lasers, whereby the individual laser outputs in the form of the terminators 26 are arranged on a circular segment and beam at a common cross-over point 185. This arrangement is particularly suitable for directly modulatable lasers since a very low expense then results. In such an arrangement, the imaging on the processing surface 81 can occur with only a single lens 186. However, an arrangement according to Figs. 4b or 4c can also be employed for imaging. The ray cones of the ray bundles from the terminators are set such that a beam narrowing and, thus, a sharp image derives for all lasers on the processing surface 81. Preferably, the spacings between the cross-over point 185 and the lens 186 as well as between the lens 186 and the processing surface 81 are of the same size and correspond to the focal length of the lens 186. In this case, the axes of the individual ray bundles between the lens 186 and the processing surface 81 are parallel and yield constant spacings between the processing tracks, even given a modified distance between the laser gun and the processing surface. Although not shown, a plurality of levels of lasers can also be arranged above one another in order to increase the power

density and the power of the laser radiation source. The planes of the lasers are preferably arranged parallel to one another. As shown in Figs. 29 and 31, it then derives that the individual ray bundles from the individual planes meet on a spot in the processing points on the processing surface 81 and thus generate an especially high power density.

Fig. 24 shows a modification relating to Fig. 23. Four fiber lasers F_{HD1}, F_{HD2}, F_{HD3}, F_{HD4} have their terminators 94, which are described in greater detail in Figs. 10, 10a and 10b, joined to one another on a circular segment. The terminators 94 are particularly suited for joining to one another as a result of their shape. Since no directly modulatable fiber lasers are employed here, a four-channel acousto-optical modulator 34 is inserted. The piezo-electric sensors 45 can, as shown in Fig. 24, likewise be arranged on a circular segment. As shown in Fig. 24a, however, they can also be arranged parallel as long as the ray bundles are still adequately acquired by the acoustic field of the piezo-electric sensors 45. Instead of the lens 186, a transmission unit as described in Figs. 4b and 4c is advantageously employed.

Fig. 25 indicates a demagnifiying intermediate image with the lense 191 and 192, so that the distance between the individual terminators 26, 94 can be greater than the distance between the individual modulator channels T1 through T4 on the multi-channel acousto-optical modulator 34. The imaging ratio corresponds to the relationship of the focal lengths of the two lenses 191 and 192. The intermediate image is preferably telecentrically designed in that the distance of the lens 191 from the lenses 133 of the terminators 26 or 94 and from the cross-over point 193 is equal to its focal length, and in that the distance from the crossing point 193 to the lens 192 as well as the distance of the lens 192 from the modulator crystal 34 is equal to its focal length. By adjusting the distance between the two lenses, however, one can also achieve that the rays emerging from the lens 192 no longer proceed parallel but at an angle relative to one another in order to connect the beam path according to Figs. 21 or 22 thereto. An intermediate image according to Fig. 25 can also be employed in combination

with an arrangement of the terminators on a circular segment according to Figs. 23 and 24.

The intermediate image (191, 192) is shown in Fig. 25 between the terminators (26, 94) and the modulator (34). However, a wavelength-dependent or polarization-dependent mirror 37 can also be arranged preceding or following the intermediate image in the beam direction. An intermediate image (191, 192) can also be arranged in the beam path following the modulator, before or after the strip mirror 46. Preferably, the intermediate image in the beam path is inserted at the locations referenced "E" in Fig. 4a.

Figs. 26 and 26a show how the distance between the tracks in the processing plane can be reduced. Fig. 26 is a side view and Fig. 26a is the appertaining plan view. Since the ray bundles 144 emerging from the terminators 26, 94 have a smaller diameter than the housing of the terminators, interspaces remain that are not utilized. Moreover, the minimum distances between the tracks and the maximum diameters of the ray bundles are prescribed by the multi-channel acoustic-optical modulators 34. In order to increase the distances between the tracks, a strip mirror 46 is provided that is transparent and mirrored in alternating fashion in stripe-shaped fashion at intervals. The strip mirror 46 and the modulators are not shown in Fig. 26a. Such a strip mirror 46 is shown in Figures 27 and 27a, whereby Fig. 27a shows a side view of Fig. 27. Highly reflective strips 195 are applied on a suitable substrate 194 that is transparent for laser radiation. The interspaces 196 as well as the backside are preferably provided with a reflection-reducing layer. The ray bundles 144 from the terminators 26, 94 of the fiber lasers F_{D1} through F_{D4} pass unimpeded through the transparent part of the strip mirror 46. The ray bundles 144 from the terminators 26, 94 of the fiber lasers F_{R1} through F_{R4} are arranged such that they are reflected at the strips of the strip mirror such that that they lie in a row with the ray bundles F_{D1} through F_{D4}. The distance between the tracks has thus been cut in half.

Fig. 27b shows a strip mirror 46, whereby the substrate of the mirror was removed in the interspaces 196, and the entire, remaining surface is preferably

highly reflectively mirrored, so that strips 195 derive. In this case, the strip mirrors can be preferably manufactured of metal, which is especially advantageous given high powers and the heating connected therewith.

An arrangement having strip mirrors can be combined very well with an arrangement having wavelength-dependent mirrors, as shown, for example, in Figures 4, 4a, 4b, 4c. The further beam path according to Fig. 20 can be connected vi the lens 55. The axes of the individual terminators 26, 94, however, can also be arranged at an angle, as shown in Figs. 23 and 24. In this case, the further beam path can proceed according to Fig. 21 or 22 and the lens 55 is omitted.

Figs. 28 and 28a show how fiber lasers of different wavelength, for example Nd:YAG lasers having 1060 nm and those having a different doping with 1100 nm are combined with one another via a wavelength-dependent mirror 37. The wavelength difference can be less but can also be greater.

The modulators and the wavelength-dependent mirror are not shown in Fig. 28a. Preferably, wavelength-dependent mirrors are optical interference filters that are manufactured by vapor-deposition of suitable dielectric layers onto a substrate that is transparent for the appertaining wavelengths and can have very steep filter edges as high-pass or low-pass filters. Wavelengths up to the filter edge are allowed to pass; wavelengths beyond the filter edge are reflected. Band-pass filters are also possible. Likewise, lasers of the same wavelength but a different polarization direction can be combined via polarized beam combiners, preferably polarization prisms. Inventively, a combination of polarized beam combiners and wavelength-dependent mirrors is also possible. In Fig. 28, the ray bundles 144 emerging from the terminators 26, 94 of the fiber lasers F_{HD1} through F_{HD4} with the wavelength λ_1, pass unimpeded through a wavelength-dependent mirror 37, whereas the ray bundles F_{VD1} through F_{VD4} having the wavelength λ_2 are reflected at it and, thus, the two ray bundles are united in one another following the mirror. Each ray bundle can be separately modulated according to the invention via a respective multi-channel, acoustic-optical modulator 34. Since

respectively two lasers of different wavelengths process the same track in the same processing point on the processing surface, a digital amplitude modulation in 2 stages is possible in a simple way in order, for example, to control the depth of the cups when producing printing forms for rotogravure when the two participating ray bundles are respectively merely turned on or off. However, a shared modulator for the two united ray bundles can also be employed. In this case, the modulator is arranged between the wavelength-dependent mirror 37 and the lens 55, as shown in Figs. 4, 4a, 4b, 4c. The further beam path of the transmission unit according to Fig. 20 connects via the lens 55. However, the axes of individual terminators 26, 94 can also be arranged at an angle relative to one another, as shown in Figs. 23 and 24. In this case, the further beam path can proceed according to Fig. 21 or 22 and the lens 55 can be omitted.

Fig. 29 shows how fiber lasers with their terminators 26, 94 (Fig. 31) can be arranged in a plurality of planes. Three planes of terminators that are connected to fiber lasers lie above one another. The first track is referenced F_1 for the first plane, with F_2 for the second plane and with F_3 for the third plane. The numerals 11, 12 and 13 reference the first plane of the further tracks. The axes of the ray bundles 144 emerging from the terminators are directed parallel to one another in the individual planes. The axes of the ray bundles of the individual tracks can proceed parallel to one another, as shown in Fig. 20, or at an angle relative to one another according to Fig. 23 or 24.

In Fig. 30, the terminators 26, 94 (Fig. 31) of, for example, seven fiber lasers F_1 through F_7 are arranged in a hexagon such that the axes of their ray bundles 144 are parallel to one another. To this end, terminators according to Fig. 12 can be advantageously employed. As a result thereof, the smallest possible diameter of a common ray bundle composed of seven individual ray bundles derives.

First, Fig. 31 is a sectional view through the three planes of the first track of Fig. 29. A lens 107 collects all incoming parallel rays in its focal point 201 on the processing surface 81. As a result thereof, power and power density are

multiplied by the plurality of lasers united in the focal point, i.e. are tripled given three planes. When the axes of the ray bundles emerging from the terminators 26, 94 proceed parallel to one another for tracks and planes, the ray bundles of all tracks would likewise be additionally united in the focal point, and a common processing point would arise on the processing surface that generates a processing track. I.e., the same number of processing tracks are registered next to one another as there are tracks of terminators. The power of the ray beams of the various planes is superimposed in the respective processing point and the power density is tripled in the illustrated example. The individual fiber lasers can thereby be directly modulated; however, external modulators can also be employed. Figs. 32 and 33 describe how a multiple-channel acousto-optical modulator corresponding to the number of tracks can be preferably employed for the simultaneous modulation of all ray bundles of the various planes.

Fig. 31 is also a sectional view through the bundle arrangement according to Fig. 30. It is known that parallel ray bundles that are incident into a lens have a common focus. Page 13, Fig. 2.21 in the book "Optik und Atomphysik" by R. W. Pohl, 13th edition, 1976, Springer Verlag shows such an arrangement. Further, DE-A-196 03 111 discloses an arrangement wherein, as can be seen from Fig. 1 therein, the radiation from a plurality of laser diodes is respectively coupled into a single-mode fiber, the radiation at the output of each fiber is collimated to a respective, parallel ray bundle, and all parallel ray bundles are directed onto a common spot with a shared lens in order to achieve an increased power density. Compared to the arrangement shown in Fig. 31 with fiber lasers, however, this arrangement has serious disadvantages. When radiation is to be efficiently coupled into single-mode fibers, single-mode laser diodes are required for this purpose so that the aperture of the single-mode fibers is not overfilled and the total radiation can be transmitted into the core of the single-mode fiber. Single-mode laser diodes, however, can only be manufactured with extremely limited power because the loadability of the minute laser mirrors represents a technological barrier. Single-mode laser diodes are therefore only available up to

an output power of approximately 200 mW and are far more expensive per watt then multi-mode diodes that are offered with radiation powers of up to several kilowatts. Given single-mode fibers for 800 nm wavelength, the product of core diameter and numerical aperture amounts to approximately 5 μm x 0.11 = 0.55 μm, whereas this lies at 300 μm x 0.4 = 120 μm given a fiber laser having a typical diameter of the pump fiber of 300 μm and a numerical aperture of 0.4, which amounts to a factor of 220. When the area ratio of the two fibers is considered, then a factor of $(300/5)^2 = 3600$ derives. Even when a reduction of the laser radiation by the factor of the absorption efficiency of approximately 0.6 is assumed given the fiber laser, this being the efficiency with which the pump radiation is converted into laser radiation, the power of the laser radiation that can be achieved at the output of a fiber laser is several orders of magnitude higher then the power at the output of a single-mode fiber. Even if single-mode diodes or other laser radiation sources having very high power were available, it would nonetheless not be possible to couple this satisfactorily into single-mode fibers, since the fibers would burn given the slightest misadjustment at the fiber entry. This problem does not exist given fiber lasers since a relatively large fiber diameter is available for the pumping and the energy is transmitted into the single-mode core of the laser fibers only within the laser fiber, which is possible unproblemmatically and with good efficiency.

The lens 197 in Fig. 31 unites the entire power of all seven ray bundles F_1 through F_7 of the corresponding fiber lasers in its focal point 201 which represents the processing spot 24 on the processing surface 81. The power and the power density in the focal point thus become higher by the factor of 7 than is the case given an individual ray bundle. When, for example, 100 W are required in order to generate a required power density on the processing surface, then seven lasers having a radiant power of approximately 15 watts each suffice in this case. However, more than seven lasers can be provided. The lasers can preferably be directly modulated. However, it is also possible to modulate all seven ray bundles separately or overall with an external modulator or to supply a plurality of such

bundle arrangements to a multi-channel modulator in such a way that the modulator channels are preferably arranged in the focal point of a uniting lens 197 that is allocated to each bundle. It is also possible to couple the multiplied power of each and every bundle into fibers before or after the modulation. Further, such bundle arrangements can be advantageously utilized in laser guns according to Figs. 4, 4a, 4b, 4c.

It is advantageous to separately modulate the individual lasers. This is especially suitable when a high number of lasers is employed, since, for example, a quantized modulation that is similar to an analog modulation, a quasi-analog modulation of the united laser radiation is then enabled by digital modulation of the individual lasers. However, it is also possible to modulate the ray bundles 144 of all lasers in common, for example with an acousto-optical modulator. In this case, the ultrasound field of the modulator cell must exhibit such a size that the overall ray bundle shown in Fig. 30 can be modulated. However, the switching time of the acousto-optical modulator becomes so great as a result thereof that the shape of the cups to be engraved is disturbed as a consequence of the rotational movement of the drum containing the processing surface. However, it is possible to entrain the laser beam with a deflection motion in the direction of the rotary motion of the printing cylinder to be engraved during the engraving and to thereby achieve a processing spot 24 that is stationary on the processing surface. Inventively, the deflection motion can occur with the same acousto-optical modulator with which the amplitude modulation occurs. However, another acousto-optical cell can also be utilized, the deflection occurring therewith.

Fig. 32, in a farther-reaching example, shows how the power density on the processing surface can be considerably increased by providing terminators 26, 94 with the corresponding fiber lasers in a plurality of planes, but a modulation of all ray bundles 144 belonging to a track can be simultaneously implemented with a single-multi-channel, acousto-optical modulator 34 corresponding to the plurality of tracks. In this example, the terminators are arranged in three planes of n tracks each that lie above one another. The power of all ray bundles 144 of all

planes should be largely focused in a processing point in the processing surface for each track in order to achieve a high power density. The terminators 26, 94 are arranged parallel to one another in tracks and planes, since the terminators 26 are joined to one another in close proximity. As shown, terminators having a round cross-section can be employed for this purpose; preferably, however, terminators having a quadratic cross-section according to Figs. 9 and 9a are utilized. Given the parallel arrangement of the tracks, the illustrated imaging system having the cylindrical lenses 202 and 203, also refer to as cylinder optics, can, for example, be added analogous to an arrangement like that of Fig. 4. When the individual tracks are to proceed at an angle according to Figs. 23 or 24, terminators 94 according to Figs. 10, 10a and 10b are preferably employed. In this arrangement, too, the ray bundles of the individual planes remain parallel; the fits of the terminators 94 should proceed parallel in the side view of Fig. 10a for this purpose. When the axes of the ray bundles for the tracks proceed at an angle relative to one another, the cylinder optics having the lenses 202 and 203 can be added, for example analogous to the arrangements according to Figs. 4b or 4c. The ray bundles 144 emerging from the terminators are directed onto the convex cylinder lens 202 that would ignite the rays in its focus to form a line having the length of the beam diameter. A concave cylinder lens 203 having a shorter focal length then the cylinder lens 202 is attached such in the region of the focus of the cylinder lens 202, 203 having a long focal length such that its focus coincides with the focus of the cylinder lens 202. As a result thereof, the rays that leave the lens 203 become parallel again. The spacings between the individual planes, however, have been reduced by the ratio of the focal lengths of the two cylinder lenses compared to the spacings that the ray bundles had when they left the terminators 26, 94. The spacings of the ray bundles have remained unmodified in the direction of the tracks since the cylinder lenses exhibit no refractive effect in this direction. As a result thereof, elliptical beam cross-sections derive in the modulator. The purpose of this arrangement is to make the overall height of the three ellipses lying above one another so small that it approximately corresponds

to the major axis of the ellipses in order to create conditions in the channels of the acousto-optical modulator similar to those achieved given a round beam cross-section so that, for example, similarly short switching times can be achieved.

Fig. 33 shows that, however, the spacing of the two cylinder lenses can also be modified somewhat so that all three elliptical ray bundles overlap in the modulator, this is in fact yielding a shorter switching time in the acousto-optical modulator but also yielding an increased power density in the modulator crystal. The cylinder lens 203 can also be omitted for this purpose.

The cylinder optics (202, 203) is shown in Fig. 25 between the terminators (26, 94) and the modulator 3. However, a wavelength-dependent or polarization-dependent mirror 37 can also be arranged preceding or following the cylinder optics in beam direction. A cylinder optics (202, 203) can also be introduced in the beam path following the modulator, preceding or following the strip mirror 46. Preferably, the intermediate image is inserted in the beam path at the locations references "E" in Fig. 4a.

For removing the material eroded from the processing surface, Fig. 34 shows a mouthpiece 82 whose main job is to use a directed flow to see to it that optimally no clouds of gases and/or eroded material form in the optical beam path between objective lens and processing service 81, these clouds absorbing a part of the laser energy and depositing on the processing surface and thus negatively influencing the work result.

As a result of its specific shaping, the mouthpiece 82 prevents the described disadvantages. Preferably, it is secured to the laser gun with connections 204 that are simple to release, so that it can be removed and cleaned in a simple way and also enables a simple cleaning as well as a simple replacement of the objective lens (not shown) 61, 103, 112. A cylindrical bore 206 for adaptation to the objective lens and a preferably conical bore 207 as passage for the ray bundle as well as another preferably cylindrical bore that represents the processing space 211 are located in a preferably cylindrical base member 205. The distance of the base member 205 from the processing surface

81 should not be excessively great. The processing points (not shown) for producing the individual processing tracks on the material to be processed lie in the processing spot 24. A broad, all around extraction channel 212 is preferably located in the base member, this channel 212 being connected to the processing space 211 via a plurality of extraction channels 213 that should have a large cross-section. Preferably, 3 through 6 extraction channels 213 are present. A further, preferably all around admission channel 214 is located in the base member, this channel 214 being connected via nozzle bores 215 to the processing space 211 and to the conical bore 207 via smaller bypass bores 216. 3 to 6 nozzle bores 215 and 3 to 20 bypass bores 216 are preferably distributed over the circumference of the admission channel 214. All bores can be offset relative to one another and relative to the extraction channels 213 on the circumference. Further bypass bores can also be attached and directed onto the objective lens. This, however, is not shown. The base member is surrounded by a ring 217 applied gas-tight that contains a plurality of extraction connectors 221 in the region of the channel 212 to which extraction hoses are connected, these being conducted via an extraction filter to a vacuum pump. The extraction hoses, the extraction filter and the vacuum pump are not shown in Fig. 34. In the region of the channel 214, the ring contains at least one admission connector 222 via which compressed air filtered with an admission hose is supplied. The quantity of admitted air can be set with a valve such that it is just adequate in order to adequately rinse the processing space and such that it generates a slight air stream along the conical bore via the bypass bores that largely prevents a penetration of particles into the conical bore. The admission hose, the valve and the filter are not shown in Fig.3 4. The nozzle bores 215 are directed such onto the processing spot 24 such that the clouds of gas, solid and molten material arising in the processing are quickly blown out of the beam path so that these absorb as little laser energy as possible and cannot negatively influence the processing result. Oxidation-promoting or oxidation-inhibiting gases or other gases can also be blown in with the admission air, these having a positive influence on the processing process. A slight quantity of air

from the environment co-flows through the processing space to the extraction channels through the gap between the processing surface and the base member 205; this, however, is not shown. The filter in the extraction line is attached easily accessible in the proximity of the mouthpiece and sees to keeping the vacuum pump clean. It is also possible to introduce the filter directly in the extraction channel 212. As described under Fig. 39a, it is useful when a protective atmosphere is additionally conducted over the objective lens. If the mouthpiece 82 becomes too hot due to the laser radiation reflected from the processing surface and the air that flows through does not suffice for cooling, then the mouthpiece can be provided with additional bores through which a coolant is pumped; this, however, is not shown in the Figs. A glass plate 218 that is highly anti-bloomed on both sides and is simple to change can also be located within the cylindrical bore 205, this glass plate 218 keeping dirt particles away from the objective lens. The shape of the mouthpiece can also deviate from the form that is described and shown. For example, the bores need not be cylindrically or conically implemented, as described; they can be varied in shape. Likewise, for example, the nozzle bores and extraction channels can assume arbitrary shapes and can also be asymmetrically arranged. For example, the nozzle bores in Fig. 34 can be arranged more in the upper part of the Fig., whereas the extraction channels lie more in the lower part of the Figure. For example, the nozzle bores and/or the bypass bores can also be foregone. The shape of the mouthpiece can also be modified, particularly when the shape of the processing surface and the type of relative motion between processing surface and laser radiation source demand this. It is conceivable to utilize a modified form of the described mouthpiece when the material to be processed is located, for example, on a planar surface instead of on a drum surface, and the laser radiation is conducted past this line-by-line. In this case referred to as flatbed arrangement, which is shown in greater detail in Figures 43, 43a and 43b, the mouthpiece is implemented elongated corresponding to the line length and is provided with an elongated processing space corresponding to its length. The mouthpiece is equipped with

nozzle bores and extraction channels from one or from both sides. In this case, the glass plate would be given a rectangular shape and would extend over the entire length of the arrangement. In this case, Figure 34 could be analogously considered as a cross-section of the elongated mouthpiece. Even when the material to be processed is located in a hollow cylinder, which is not shown in detail in Figs 44a and 44b, a similar mouthpiece can be produced in that the mouthpiece described for the flatbed arrangement is adapted in the longitudinal direction to the shape of the hollow cylinder such that a slight gap between the processing surface and the mouthpiece derives over the entire length. The glass plate would be given a rectangular shape in this case and would be curved over the entire length of the arrangement.

In a known scraper device that, however, is not shown in the figures can be located in the proximity of the mouthpiece but need not necessarily be connected to it or to the laser gun. For example, the job of the scraper device is to scrape off the ejects arising at the edges of the cups during the processing process at rotogravure forms. Further, a brush device (not shown) can preferably be located in the proximity of the laser gun, this brushing out the cups that have been cut and ridding them of adhering dirt. Further, a measuring device (not shown) can be preferably inventively located at the laser gun, this measuring the position and/or the volume of the cups immediately after they are produced. In contrast to cups that have been manufactured by electro-mechanical engraving or with a single laser beam, the volume can be inventively more precisely identified for cups that are produced with the inventive laser radiation source and have steep edges and constant depth, in that the area of the cup is determined with a specific, fast camera and the volume is derived therefrom. It is thereby advantageous to measure a series of cups in order to reduce measuring errors. It lies within the framework of the invention that specific control fields are engraved in a region of the rotogravure cylinder, this being provided for monitoring measurements and/or for monitoring prints. A rated/actual comparison can be produced with this measured quantity for the generated cups and with the cup size prescribed for this

location. The result can then be employed in order to correct the position and/or the volume of the subsequently produced cups.

Fig. 35 shows the conditions on the processing surface. The processing points are identified with the indices that indicate the ray bundles of the fiber lasers according to Figs. 4, 4a, 4b and 4c that produce them. For example, the ray bundles of the fiber lasers F_{VR1} and F_{HR1} generate the processing point $B_{FVR1+FHR1}$ in common to the diameter of the processing points is referenced B, and their spacing is referenced A. In the multi-channel, acousto-optical modulator described under Figs. 19 and 19a, the allowable diameter of the ray bundle 144 is smaller than the spacing of the channels of the modulator. The diameter of the ray bundle 144 in the terminators 26, 94 can also be made just as large as the outside diameter of the terminators without great expense. It follows therefrom that A is thus greater than B. This leads to undesired interspaces at the processing tracks 224 that derive as a result of the relative motion between the material to be processed and the laser gun. The processing tracks have a track width D that corresponds between the diameter of the processing points B and R referenced 1 through 8 in Fig. 35. In order to reduce these interspaces, two beam packets were already nested inside one another with the strip mirror, as described under Figs. 4, 4a, 26 and 26a, in order to cut the interspaces in half. In order to reduce the remaining interspaces even more, or to entirely avoid them or cause the processing tracks 224 to overlap, the laser gun can be turned such compared to the relative motion direction between the material to be processed and the laser gun such that the tracks come closer to one another, this being shown in Fig. 35. In order, for example, to achieve a spacing C of the processing tracks 224 that is equal to the diameter B of the processing points, the laser gun must be turned by the angle β according to the relationship $\cos \beta = B/A$. Distortions in the image information arise on the processing surface due to the rotation of the laser gun, since the starts in the individual processing tracks are now shifted relative to one another. These distortions, however, are already compensated in the editing of the processing data. It is also possible to undertake this compensation by an

adjustable, different delay of the signals in the individual data channels immediately before the modulation or to simply accept the distortions. Further possibilities for setting and reducing the spacings of the processing tracks are presented in Figs.36, 36a, 36b, 36c and 37.

Fig. 36 shows the principle of how processing points $B_1...B_4$ derive on the processing surface 81 when the individual channels are charged with different frequencies f_1 through f_4 in a multi-channel acousto-optical modulator 34 having four separate channels. For example, the modulator channel T_1 (Fig. 36a) is thereby supplied with a frequency f_1, whereby f_1 is provided with a higher frequency compared to f_4 in the modulator channel T_4 (Fig. 36a), so that a greater spacing of I_0 derives for the processing track 1 than for the processing track 4. The channels T_2 and T_3 are provided with corresponding frequencies f_2 and f_3 in order to achieve the illustrated arrangement of the processing tracks 224. However, the frequencies can also be arranged such that the frequency f_1 is lower then the frequency f_4. It is also possible to arbitrarily allocate the frequencies f_1 through f_4 to the individual modulator channels T_1 through T_4. In this case, a lens 165 as shown in Fig. 17 and Fig. 36a is not absolutely necessary; rather, the laser radiation emerging from the terminators can be focused such that a sharp image derives in the processing points on the processing surface.

How the ray bundles focused by the lens 165 impinge the generated line M of the drum is shown in Fig. 36a with reference to an example (not to scale) with the rotating drum on which the processing surface 81 lies. The position of the puncture points P of the ray axes with the plane of the lens 165 thereby corresponds to the principle of Fig. 36. For that purpose, the modulator 34 with the channels T_1 through T_4 is correspondingly arranged relative to the ray bundles 144 of the fiber lasers F_1 through F_4. What is achieved by a suitable selection of the frequencies f_1 through f_4 is that the partial rays that generate the processing points B_1 through B_4 lie at desired distances from one another in the direction of the generated line M. This has the advantage that the position of each processing point and, thus, of each processing track 224 can be individually set by adjusting

the corresponding frequency. A particular advantage of the arrangement derives when, as indicated in Fig. 17, the multi-channel acousto-optical modulator is arranged approximately in the one and the processing surface is arranged approximately in the other focal point of the lens 165, and the axes of the ray bundles of the fiber lasers F_1 through F_4 are arranged approximately in parallel planes. The processing points B_1 through B_4 then lie in a row on the generated line M (36a), and the axes of the partial rays that form the processing points are parallel and reside perpendicularly on the processing surface (Fig. 17). Another advantage of the arrangement is that the Bragg angle for optimizing the efficiency can be individually set for each modulator channel, but this is not shown in the Figures. In this example, the deflected rays are used for processing material, whereas the non-deflected rays I_0 are blanked out by an intercept arrangement similar to that shown in Figure 18. In contrast to the arrangement in Figure 18, it is shown here that the mirror 166 acting as intercept arrangement can also be arranged between the lens 165 and the processing surface. As described under Fig. 4, however, the intercept arrangement can also be foregone when a symmetrical or asymmetrical defocussing reduces the radiation that is contained in I_0 and is unwanted for processing in terms of its power density to such an extent that no processing effect is produced when it is directed onto the processing surface.

Fig. 36b shows an expanded embodiment of Fig. 36a in a side view. The lenses 202 and 203 are inserted between the multi-channel modulator with the channels T_1 through T_n, said lenses 202 and 203 being preferably cylinder lenses and forming a cylinder optics, as described under Fig. 32 and Fig. 33. This cylinder optics demagnifies the distance between the channels T_1 and T_n at the location of the lens 166 and, given a predetermined focal length of the lens 165, thus, the angle at which the rays of the individual channels T_1 through T_n impinge the processing surface, is particularly significant given a great number of channels and significantly favors the costs for the lens 165, which can also be a system composed of a plurality of lenses, as well as its makeability.

Fig. 36c shows a plan view relating to Fig. 36b, from which it can be seen that the cylinder optics exhibits essentially no effect in this view. The ray bundles F_1 through F_n coupled into the acousto-optical modulator 161 are in fact shown under the same Bragg angle; however, they can also, however, be coupled in individually differently under the respectively optimum Bragg angle.

Fig. 37 emphasizes another advantage of the arrangements according to Figs. 36, 36a, 36b and 36c, namely that respectively two processing points B_{11}, B_{12} through B_{41}, B_{42} can now be generated instead of the processing points B_1 through B_4 by simultaneous application of two different frequencies to the respective modulator channels. Instead of four processing tracks, eight separately modulatable processing tracks 224 have now arisen without increasing the number of lasers and/or the number of modulator channels. It lies within the scope of the invention to also employ more than two frequencies per modulator. Twelve different frequencies with a single modulator channel have already been realized for a similar purpose. Another advantage in the generation of processing points with acousto-optical deflection is the possible shift of the processing points at high deflection speed. By modifying the applied frequencies, individual or all processing tracks 224 can be very quickly displaced relative to their previous position and there is thus a further possibility of beneficially influencing the position and shape of the cups. With this technique, in particular, the position of the processing tracks can be correspondingly readjusted to a rated quantity with high precision. Precisions of a fraction of a track width are thereby possible. Inventively, the actual position of the individual processing tracks can be precisely determined with a known, interferometrically functioning measuring system in that, for example, the actual position of the laser radiation source is registered during the processing event and a correction signal for the required displacement and readjustment of the processing tracks is generated by comparison to the rated position of the processing tracks. This can be of interest particularly when a seamless joint is to be made to a processing pattern that already exists or when a pattern that already exists is to be post-processed.

Another enormous advantage of the arrangement is that the Bragg angle can be individually set for optimizing the efficiency for each modulator channel, which, however, is not shown in the Figures. Up to now, acousto-optical arrangements wherein a plurality of sub-beams are generated from a laser beam by applying a plurality of frequencies wherein all of these have a shared Bragg angle for all sub-beams, has not yet made a breakthrough in processing of materials because the efficiency is too low. When, however, a combination of a number of laser beams having respectively individually set Bragg angle and a number of acousto-optically generated sub-beams per laser beam is selected as proposed, then a clearly higher efficiency can be achieved, so that a great plurality of simultaneously acting processing tracks can be realized for processing material.

As described under Figs. 18 and 18a, however, single-channel or multi-channel electro-optical modulators can also be utilized in conjunction with a birefringent material in order to split each laser beam into two beams that can be separately modulated via further electro-optical or acousto-optical modulators.

It has been emphasized that the processing of the material in Figs. 36, 36a, 36b, 36c and 37 should occur with the deflected laser beams and that the radiation contained the non-deflected ray laser beam is to be neutralized, so that no processing effect is produced. This, however, is not absolutely necessary, and instances are conceivable wherein one works conversely. A further advantage of the arrangement shall therefore be cited and explained with reference to Fig. 36a wherein one wishes to employ the radiation contained in the laser beams I_0 for processing material, the mirror 166 is removed. The entire radiant power from all four lasers F_1 through F_4 thus derives on the generated line in a spot. More than four times the power density thus derives in the spot compared to the previous processing points B_1 through B_4, and it can be assumed that no processing effect arises in B_1 through B_4 given specific materials and process parameters. Ie., the processing surface simultaneously serves as a sump for the radiation that is not intended to produce any processing effect. This is advantageous since a thermal equilibrium occurs on the processing surface since the entire laser energy is

supplied to the processing surface in every case. It lies within the scope of the invention that fewer or more than four lasers with corresponding modulator channels are utilized and that the difference in the power density between the radiation that is intended to produce a processing effect and the radiation that should not produce any processing effect is increased per modulation channel by employing more than one frequency per modulator channel. It also lies within the framework of the invention that the described principle can be advantageously applied when the laser beam incident into the acousto-optical modulator has high divergence, as is the case, for example, when the acousto-optical modulator in an arrangement according to Fig. 31 is to be arranged in the proximity of the focal point 201 or in arrangements wherein the laser has an especially great divergence. In Fig. 31, for example, the axis of the ray bundle emerging from the laser F_2 is intended to represent the position of the optimum Bragg angle for a specific frequency. In this case, the Bragg condition is met far more poorly for the one frequency for the rays at the edge of the ray bundle, for example of the lasers F_1 and F_3, than for the central rays of, for example, the laser F_2, and only a slight part of the radiation is deflected, which means low contrast for the modulator. When, however, a plurality of frequencies are simultaneously applied to the acousto-optical modulator and when these frequencies are selected such that they are optimum both for the outer as well as for the middle incident ray bundle with respect to the Bragg angle, the highest possible contrast derives and the highest possible difference in the power density arises on the processing surface between the radiation that is intended to produce a processing effect and the radiation that should not produce any processing effect.

Fig. 38 shows how a flexible arrangement of the components in the optical beam path can see to it that the laser ray bundles never perpendicularly impinge the optical surfaces. This prevents a part of the radiation from being reflected from these surfaces back into the lasers. When energy proceeds back into a laser, an excitation occurs in the laser and the laser begins to oscillate in terms of the amplitude of the radiation that is output. The output power is thus no longer

constant and patterns are formed in the process surface that can make the result unuseable. Fig. 38 shows the axial rays of two planes; the lasers, however, can also be arranged in one or more planes as long as the symmetry axis for the two axes that are shown is not used. For reasons of function, the acousto-optical modulator is already turned by the angle α_B. In order, however, to be certain that energy is not reflected back into the laser as a consequence of the changing ultrasound field, the modulator can be additionally turned by the angle γ, as shown in Fig. 38. Another possibility for avoiding oscillations of the laser is the insertion of one or more optical components at suitable locations in the beam path that only allow laser radiation to transmit in one direction. For example, what are referred to as Faraday isolators can be employed for this purpose, as described under Fig. 20 in the catalog of Spindler and Hoyer on page F2. Such isolators are not shown in the Figures.

Fig. 39 shows a lens 101 whose mount contains bores 87 that preferably surround the lens in a plurality of turns and have a coolant flowing through them. Given high-power arrangements, the absorption of the optical medium of the lenses can be left out of consideration. Moreover, a slight part of the radiation is dispersed by every optical surface even given the best anti-blooming and is absorbed by the mount parts. A cooling of the lens mounts is therefore meaningful. It has already been mentioned that materials having high thermal conductivity and low absorption such as, for example, sapphire are advantageous for the most stressed lenses. Sapphire also has the advantage that the lens surface does not scratch when cleaning due to the greater hardness of the material. One should also see to a good contacting of the optical medium with the mount. This is advantageously achieved by a metallization of the edge zone of the optical element and by a soldering 223 to the mount. Metallic solders [...] a better heat conduction than glass solders.

It is also possible to cool the critical component parts of the laser gun 23 and of the pump source 2 with the assistance of what are referred to as micro-

channel coolers, as described in the article "Lasers in Material Processing" in the publication SPIE Proceedings, Vol. 3097, 1997.

Fig. 39a shows a section through an inventive mount 118 for the objective lens 61, 103, 112 that, for example, is secured with a thread to the tube body 95, 96 or to the mount 116 and is sealed with a seal 125. The objective lens can be glued into the mount or, preferably can be metallized at its edge and soldered into the mount. The mount can be provided with one or more bores 120 through which a protective atmosphere that comes from the interior of the optical unit 8 flows and, for example using a channel 119, is conducted via the side of the objective lens 61, 103, 112 pointing toward the processing surface in order to prevent a contamination of the objective lens by particles of material or by gases that are released during the processing.

Fig. 40 describes a further possibility for preparing fiber lasers or optical fibers, preferably single-mode fibers, for an arrangement in tracks and planes with small spacing. The fiber 28 or laser fiber 5 is ground on all sides at the last end to such an extent that a side length arises that is reduced to such an extent that the exit points of the laser radiation 13 lie at a required, slight spacing. In this case, the terminators 26, 94 can be omitted, and an especially simple structure derives. The surfaces that reside opposite can thereby proceed in pairs parallel to one another or at an angle, or one pair proceeds parallel and the other pair proceeds at an angle relative to one another, as was already described for the terminators under Figs. 9 and 10.

Fig. 40a shows a plan view onto, or a cross-section through the ground laser fiber. The cross-section can preferably be rectangular or quadratic; however, it can also have all other shapes.

Fig. 40b shows a side view of the fiber bundle wherein the fibers were processed similar to Fig. 40, so that the axes of the individual ray bundles 13 proceed nearly parallel.

Fig. 40c represents a side view of the fiber bundle wherein the fibers were processed wedge-shaped, so that the axes of the individual ray bundles 13 intersect outside the fiber bundle.

Fig. 40d again shows a side view of the fiber bundle wherein the axes of the individual fibers in fact proceed parallel but the exit faces of the individual fibers are arranged at different angles ε relative to the fiber axis, so that the axes of the individual ray bundles 13 intersect within the fiber bundle.

Fig. 41 shows how a receptacle with four tracks can be produced from ground fibers or laser fibers according to Fig. 40 and Fig. 40a, Fig. 40b, Fig. 40c, 40d. A receptacle in a plurality of planes is shown in broken lines in Fig. 41 in the form of two further planes. The receptacle is also not limited to four tracks and three planes; the laser outputs can be arranged in an arbitrary number of tracks and planes according to this principle. On the basis of a corresponding shaping when grinding the fibers, it is possible to determine the spacings between the exit points of the laser radiation 13. For example, the spacing can be implemented such that the laser radiation of the individual plans overlaps on the processing surface 81 such that only tracks derive or such that the individual tracks overlap so that only planes derive. The spacings between the exit points of the laser radiation 13, however, can also be selected such that the laser rays of all tracks and all planes overlap in a point on the processing surface. For this purpose, the fiber lasers or optical fibers can also be arranged in a bundle.

The principle of the described arrangement of laser outputs in a plurality of planes or in a plurality of tracks or in a plurality of tracks and in a plurality of planes or overlapping in a point also inventively applies to the laser rays incident on the processing surface 81. A plurality of tracks or a plurality of levels or a plurality of tracks and a plurality of levels of laser beams can likewise be arranged on the processing surface according to this ordering principle or the laser beams can be arranged overlapping in a point.

The arrangement according to Figs. 40, 40a, 40b, 40c, 40d and 41 is particularly suited for directly modulatable lasers. However, external modulators

can also be employed. The emerging ray bundles can be imaged into the processing surface with the known arrangements; however, a receptacle can also be implemented, whereby the ray bundles are directly directed onto the processing surface, i.e. without transmission unit, in that, for example, the outputs of a laser radiation source according to Fig. 41 are brought extremely close to the processing surface or lie on the surface of the material in sliding fashion, this yielding an especially simple arrangement. Such a method can be employed, for example, when convergence in the surface of the material are to be excited by energy irradiation or when a material transfer is to be undertaken. In the example of a material transfer, a thin film is placed onto the material to be provided with images that, for example, can be a printing cylinder, an offset plate, an intermediate carrier or the material to be printed itself, a layer being applied to the underside of said thin film that faces to the material to be provided with images and that is stripped by energy irradiation and can be transferred onto the material to be provided with images.

Fig. 42 shows another embodiment of the laser radiation source that can be employed for multi-channel cutting and incising of, for example, semiconductor materials and as disclosed in German Patent Application P 198 40 936.2 of the assignee "Anordnung zum mehrkanaligen Schneiden und Ritzen von Materialien mittels Laserstrahlen" running parallel with and filed simultaneously with the present patent application. The terminators 26, 94 of the fibers or, respectively, fiber lasers F_a through F_n have ray bundles 144 that are focused with the lens 133 at a predetermined distance from the terminator. The diameter of the processing points B_a through B_n amounts, for example, to 20 µm; however, it can also lie thereabove or therebelow. Further, the terminators are arranged on a profiled rail 256 described in greater detail in Figs. 42 and 42b such that their mutual spacing "A" can be set to arbitrary values until the terminators meet one another. The profile rail is preferably secured to an arm of a robot (Fig. 42c) and can, for example, be moved in the directions x, y, z relative to ta table 225 with actuating drives that are shown in Figure 42c. Moreover, the profiled rail can be turned

relative to the table by an angle φ having the axis z' (Fig. 42c), which can also be utilized for determining the mutual spacing of the processing tracks. In the exemplary embodiments according to Figs. 4, 4b, 4c, 43, 44, the laser gun is turned around the axis of the tube 51, 95, 113 in order to vary the spacings between the processing tracks. Further, the table can be moved in the directions x, y, z and can be turned by an angle φ with the axis z. The material to be processed, for example one or more, what are referred to as "wafers" separated from a drawn semiconductor ingot, can be secured on the table 225 with clamp or suction devices (not shown). For example, fine, parallel tracks as needed, for example, for contacting photo-voltaic cells, can be incised into the semiconductor material with the laser energy in the individual processing points B_1 through B_n. However, fine bores can also be introduced into the semiconductor material or it can be cut with the laser in order, for example, to thus separate electrical circuits from one another. An inventive arrangement for removing the material 249 (Fig. 42c) eroded from the processing surface is attached close to the processing surface 81 for each processing track 224 separately or for a plurality of processing tracks 224 in common, the functioning of said arrangement being described in detail in Fig. 34. When the profiled rail with the terminators is turned relative to the table in order to modify the spacing between the processing tracks, it is inventively expedient to compensate the distortion of the pattern to be registered that arises due to the relative rotation by a pre-distortion of the pattern to be applied and/or to compensate it with a time control of the data stream. On the basis of the turning, it is also possible to intentionally provide different line spacings given relative motions in x-direction and in y-direction. For contacting of the photo-voltaic cells, for example, two different line patterns are required: a first pattern wherein the incised lines following the metallization produce the contact to the semiconductor material should have spacings of a few millimeters between the individual lines and should, for example, proceed in the x-direction. Further, what are referred to as bus bars are required that proceed at a right angle relative to the contact lines and connect these to one another. These lines forming the bus

bars should, for example, proceed in the y-direction and lie close to one another so that they act like a closed band following the metallization. Inventively, such a pattern can be very simply manufactured in that the profiled rail with the terminators is turned to such an extent until the desired pattern results. Due to the parallel arrangement of a plurality of fiber laser outputs, the time required for the processing can be considerably shortened; for example, ten laser outputs can be employed in parallel for the incising of the photo-voltaic elements 10, this increasing the output by the factor of 10.

The described arrangement for cutting and incising is not only suitable for processing semiconductor materials but can be employed for all materials wherein the precise production of patterns is important such as, for example, in manufacturing printing forms.

Fig. 42a and the corresponding sectional view of Fig. 42b show how the terminators 26 of the individual fiber lasers F_a through F_n are secured. The profiled rail 256 is secured to a carrier 260 with connections 261, the carrier potentially being, for example, the arm of a robot. The terminators 26 are accepted in mounts 257 and fixed with screw 259. The mounts 257 are provided with a profile mating with the profiled rail 256, are placed in a row onto the profiled rail 256, are set at predetermined intervals "A" from one another and are fixed with the screws 259. Due to an inventively small structure of the terminators 26 and of the mounts 257, a very slight spacing"A" is possible. The profiled rail with the terminators can be conducted across the processing surface with the robot for the purpose of processing the material, as shown in Fig. 42 and described in detail. The required movements for producing the processing tracks can be executed by the table 225 described in Fig. 42 that can also be carried out by the arm of the robot. Preferably, the arm of the robot can also undertake a rotatory motion around the rotational axis z' of the arrangement that is approximately parallel to the axis of the terminators. With this rotation and a relative displacement between the arm of the robot and the table 225, it is possible to modify the spacing of the processing tracks generated on the processing surface

81 and to preferably set them smaller than corresponds to the dimension "A" that has been set.

Fig. 42c indicates an example of the robot that can be constructed, for example, of components of Montech-Deutschland GmbH, Postfach 1949, 79509 Lörrach. A horizontal-linear unit 263 is secured on a stand system "Quickset" 262, the unit 263 in turn accepting a vertical-linear unit 264 having a rotatory drive 265. The actual robot arm 260 is seated at the rotatory drive, the profiled rail 256 being secured to the arm 260 with the connection 261. Another horizontal-linear unit is possible but not shown.

The various motion directions of the table 225 can be realized with the same element, whereby the motion directions can also be partly allocated to the table and partly to the profiled rail. The housing for the acceptance of individual components, the cooling system, the control for the lasers, the pump sources for the fiber lasers, and the terminators 26, 94 are shown, the arrangement for removing the material eroded from the processing surface and the machine control for the drives are not shown in the Figures.

Fig. 43 shows a further flatbed arrangement with the inventive laser radiation source. The material to be processed with the processing surface 81 is located on a table 247 that is seated on guides 251 and can be moved in the feed direction u precisely with a spindle 252. The spindle 252 is placed into rotation by a motor 254 via a gearing 253 that is driven proceeding from a control electronics 255. The laser radiation emerging from the laser gun 23 generates the processing points B_1 through B_n in an intermediate image plane 228 (not shown here) that, for example, is shown in Fig. 44. The laser radiation is conducted via deflection mirror 241 and an optics 242 belonging to an optical unit onto a rotating mirror 243 that, for example, can have one mirror face that, however, can also be designed as a rotating mirror having a plurality of mirror faces and that is placed into a rotatory motion by a motor 244 driven proceeding from the control electronics 255. The rotating mirror 243 steers the laser radiation over the processing surface line-by-line in arrow direction v. An optics 245 belonging to

the optical device is located between the rotating mirror and the processing surface, the job of the optics 245 being to generate a sharp processing spot on the processing surface over the entire line length, this processing spot being potentially composed of a plurality of processing points B_1' through B_n' that are shown in Fig. 43. As a result of the rotation of the rotating mirror, the processing points generate processing tracks 224 on the processing surface 81 as shown, for example, in Figs. 35, 36 and 37. Preferably, a long deflection mirror 246 is provided between the processing surface 81 and the optics 245 in order to achieve a compact structure. The laser gun 23 is preferably turned in the prism 248 such that the processing tracks have the desired spacing from one another on the processing surface, this being shown in Fig. 35. The fixing of the laser gun can occur with a strap retainer (not shown). An inventive arrangement 249 for removing the material eroded from the processing surface is attached close to the processing surface 81 over the entire line length, the arrangement 249 being capable of being provided with a glass plate 230 over the entire length and being shown in greater detail in Fig. 43b. In Fig. 43, a laser gun with the lenses 102 and 103 according to Fig. 4b and a beam path illustrated in Fig. 20 can be provided; however, all other types of inventive laser guns can also be used. Further, a plurality of laser radiation sources can be attached in such a flat bed arrangement in order to speed the processing procedure up. Inventively, a second laser radiation source with the corresponding optics and the arrangement 249 for removing the material eroded from the processing surface can be attached opposite the illustrated arrangement such that further processing tracks derive on the processing surface.

It lies within the framework of the invention that the rotating mirror can also be replaced by an oscillating mirror. It also lies in the scope of the invention that the rotating mirror can be replaced by two oscillating mirrors, whereby the oscillatory direction of the one mirror, called “mirror u”, lies on the processing surface 81 in the direction referenced u, and whereby the oscillating direction of

the other mirror called "mirror v", lies on the processing surface 81 in the direction referenced v.

An arrangement having oscillating mirrors is especially well-suited for fast incising of photo-voltaic cells, as was described in detail under Fig. 42. The cell to be incised is placed onto the table 247 with, for example, a loading device that is not shown in Fig. 43 and is brought into the correct position. The laser gun 23 is turned such that the desired spacings in the processing tracks arise in the two processing directions u and v. In a first processing event, for example, mirror u draws the contact lines, whereas mirror v undertakes the correct positioning of the contact line packets. In a second processing event, mirror v draws the bus bars, whereas mirror u undertakes the correct positioning of the line packets. In these processing events, the photo-voltaic cell is not moved. It lies within the scope of the invention that the table 247 can be replaced by a magazine (not shown) wherein a specific number of photo-voltaic cells are delivered for processing, that the processing of the respective cell occurs directly in the magazine, and that the processed cell is automatically removed from the magazine after the processing and is transferred into a second magazine, whereby the next, unprocessed cell for processing moves forward to take the place of the removed cell.

As a result of the extremely high beam quality of the laser radiation source that derives due to the fiber laser working refraction-limited, a nearly parallel laser beam bundle can be generated, as shown in Fig. 43 between the optics 242 and rotating mirror 243 and as can also be seen in Fig. 4 between the lenses 57 and 61. Consequently, it is also possible to remove the optics 245, the rotating mirror 243 and the deflection mirror 246 in Fig. 43 and replace them by a deflection mirror (not shown) that deflects the nearly parallel laser beam bundle emerging from the optics 242 in the direction of the processing surface 81 and onto an objective lens (not shown) having a short focal length that is implemented similar to the objective lenses 61, 103 or 112.

The deflection mirror and the objective lens are inventively combined with one another to form a unit and slide back and forth on a guide rail (not shown) in

the direction v, so that a number of parallel processing tracks corresponding to the number of channels in the laser radiation source are registered on the processing surface (81) similar to previously with the rotating mirror 243 and the optics 245.

Inventively, the guide rail is implemented as a bearing having very low friction, for example as an air bearing or as a magnetic bearing. The drive of the unit composed of the objective lens and the deflection mirror in the direction v and back respectively occurs with a thrust into the corresponding direction that, for example, is carried out by a preferably contact-free electromagnetic system, whereby the energy acquired from the deceleration of the moving unit is partially re-employed for the drive. Parts of the guide rail, deflection mirror and objective lens are, for example, accommodated in a closed space that contains windows for the entry and the exit of the laser radiation and can be evacuated in order to reduce frictional losses. The drive and guide rail represent a linear drive for the unit composed of the objective lens and the deflection mirror.

It lies within the framework of the invention that the respective, true position of the moving unit can be determined for correction purposes via, for example, an optical reference track. An arrangement 249 serves for the removal of the material eroded from the processing surface 81. The advantage of such an arrangement is that it can be very cost-beneficially realized for long path lengths and high resolutions, and that it can be set to various formats by displacement of the one and/or other drive. A plurality of such units can also be arranged in parallel in order to increase the processing speed.

Fig. 43a shows a simplification of the arrangement according to Fig. 43 in that the two lenses 102 and 103 have been removed from the laser gun. Given a corresponding spacing of the laser gun from the deflection mirror 241, the divergent laser ray bundles emerging from the lens 101 are focused onto the processing surface 81 with the lenses 241 and 245 and generate the processing points B_1 through B_n that are identical to the processing points B_1' through B_n' in this case.

Fig. 43b shows the arrangement 249 for removing the material eroded from the processing surface in greater detail. The functioning has been described in detail in Fig. 34.

Fig. 44 shows a hollow bed arrangement for processing material with the inventive laser radiation source. Hohlbett arrangements are known; for example, two arrangements having hollow bed are described in the publication "Der Laser in der Druckindustrie" by Werner Hülsbuch, Verlag W. Hülsbusch, Constanc, pages 461 and 562. The material to be processed with the processing surface 81 is located in a cylinder or, preferably, a part of a cylinder 236 having the radius R. This arrangement is referred to as a hollow bed on whose axis a bearing 229 with a rotating mirror 233 is arranged. The rotating mirror can, for example, have one mirror face but can also be designed with a plurality of mirror faces and can be placed into rotation by a motor 234 and be arranged on a carriage (not shown) displaceable in the direction of the cylinder axis relative to the cylinder 236. An optics 231 belonging to an optical device and a mirror 232 are arranged as well on the carriage (not shown) in the proximity of the processing surface 81. Further, a deflection mirror 227 and the laser gun 23 as well as an arrangement 235 - close to the processing surface 81 - for removing the material eroded from the processing surface, which is described in greater detail in Fig. 34, are located on the carriage. The ray bundles 226 emerging from the laser gun generate processing points B_1 through B_n in an intermediate image plane 228 that are transmitted onto the processing surface 81 with the deflection mirror 227, the mirror optics 231, 232 and the rotating mirror 233. Here, they generate the processing points B_1' through B_n'. The processing points B_1' through B_n' that form the processing spot generate processing tracks 224 (Figs. 35, 36 and 37) across the entire line length that are registered sharply focused over the entire line length as a result of the constant radius of the hollow bed. The advantage of the illustrated arrangement is that a compact structure can be achieved. In particular, the illustrated arrangement enables a small angle δ between the axis of the ray bundle incident onto the rotating mirror 233 and the ray bundle that is reflected by the

rotating mirror onto the processing surface, which is desirable for low distortion in the recording geometry on the processing surface. The laser gun is preferably seated in a prism (not shown) and is secured with a fastening strap (likewise not shown). The laser gun can be turned around its axis and can be displaced in the axial direction. As a result of the rotation, the distance between the processing tracks can be modified, this being shown in Fig. 35. The spacing from the processing surface can be modified by the displacement. An inventive arrangement 235 for removing the material eroded from the processing surface is attached over the entire line length close to the processing surface 81, the arrangement 235 being capable of being designed similar to what is shown in Fig. 43b, whereby it is implemented in curved fashion corresponding to the radius R of the cylinder 236 and can be provided with a curved glass plate 237 (not shown) over the entire length, the functioning thereof having been described in detail under Fig. 34. In Fig.44, a laser gun having the lenses 102 and 103 according to Fig. 4b and a beam path shown in Fig. 20 are provided. However, all other types of the inventive laser gun can be utilized. Further, a plurality of laser radiation sources can also be attached in such a hollow bed arrangement in order to speed the processing event up. For example, a second rotating mirror and a second laser radiation source as well as a second arrangement 235 for removing the material eroded from the processing surface can be attached opposite the illustrated arrangement such that further processing tracks derive on the processing surface.

Fig. 44a shows a simplification of the arrangement according to Fig. 44, in that the two lenses 102 and 103 were removed from the laser gun. Given a corresponding spacing of the laser gun from the deflection mirror 227, the divergent laser ray beams emerging from the lens 101 are focused onto the processing surface 81 with the lens 231 and generate the processing points B_1 through B_n that are identical to the processing points B_1' through B_n' in this case.

While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only the preferred embodiment has been shown and described and that all changes and modifications that come within the spirit of the invention are desired to be protected.

Abstract

In a laser radiation source, preferably for processing material, as well as to an arrangement for processing material with the laser radiation source and to the operation thereof, for achieving a high power density and energy, the laser radiation source comprises a plurality of directly modulatable diode-pumped fiber lasers whose outputs are arranged in a bundle. The laser radiation emerging from the outputs of the fiber lasers is merged and bundled with an optical unit such that the laser radiation is incident onto a processing surface at a processing spot .

WordPerfect Document Compare Summary

Original document: P:\H&S c drive\MyFiles\844\App\27021-0032-PCT.wpd
Revised document: P:\H&S c drive\MyFiles\844\App\P010032-substitute specification.wpd
Deletions are shown with the following attributes and color:
Blue RGB(0,0,255).
Deleted text is shown as full text.
Deletions are surrounded by brackets [ ].
Insertions are shown with the following attributes and color:
Underline, (No color code).

The document was marked with 374 Deletions, 461 Insertions, 0 Moves.

SPECIFICATION

TITLE

LASER RADIATION SOURCE

BACKGROUND OF THE INVENTION

The invention is directed to a laser radiation source, preferably for processing materials, as well as to an arrangement for processing material comprising a laser radiation source and to the operation thereof.

When processing materials with focused energy beams such as, for example, electron beams or laser beams, there are applications wherein structures must be produced that make high demands of the focused energy beam with respect of its beam geometry and the focusability of the beam. At the same time, however, a high steel power is required.

A typical case wherein extremely fine structures must be produced on a processing surface is the production of printing forms, whether for rotogravure, offset printing, letter press printing, silk screening or flexo-printing or for other printing processes. In the production of printing forms, it is necessary to produce extremely fine structures on the surface of the printing forms, since highly resolved image information such as text, [rastered]<u>screened</u> images, graphics and line work must be reproduced with the surface of the printing forms.

In rotogravure, the printing forms were produced in the past with etching, which had led to good results; the etching, however, was replaced over the course of time by more environmentally friendly engraving with electromagnetically driven diamond stylii. Printing cylinders whose surface is composed of copper are normally employed as printing forms in rotogravure, these fine structures required for the printing being engraved thereinto in the form of cups with the diamond stylus. The printing cylinders are introduced into a printing press after they are produced, the cups being filled with ink therein. Subsequently, the excess ink is removed with a doctor <u>blade</u> and the remaining ink is transferred

onto the printed matter during the printing process. Copper cylinders are thereby employed because of their long service life in the printing process. A long service life is required given large editions, for example, in particular, in magazine printing or packaging printing, since the surface of the printing form wears in the printing process as a result of the influence of the doctor blade and of the printed matter. In order to extend the service life even further, the printing cylinders are provided with a copper layer that has been galvanized on[or,]; on the other hand, solid cylinders of copper are employed. Another possibility of making the service life even longer is comprised in galvanically chrome plating the copper surface after the engraving. In order to achieve an even longer surface life, what is referred to as "hot chrome plating" is additionally applied, whereby the galvanic process is carried out under elevated temperature. The longest service lives that could previously be obtained were achieved therewith. Deriving therefrom is that copper is the most suitable as the material for the surface of rotogravure cylinders. Materials other than copper have not hitherto proven themselves for large editions.

When producing the cups, the drive of the diamond stylus [ensues]occurs via an electromechanically driven magnet system having an oscillating armature to which the diamond stylus is secured. Such an electromechanical oscillatory system cannot be made arbitrarily fast because of the forces that must be exerted in order to engrave the cups. This magnet system is therefore operated above its resonant frequency so that the highest engraving frequency, i.e. the highest engraving speed can be achieved. In order to increase the engraving speed even further, a number of such engraving systems have been arranged side-by-side in the axial direction of the copper cylinder given current engraving machines. This, however, still does not suffice for the short engraving time of the printing cylinders required currently, since the engraving time directly influences the current nature of the printing result. For this reason, rotogravure is not employed for newspaper printing but mainly for magazine printing.

Upon utilization of a plurality of engraving systems, a plurality of what are referred to as lanes are simultaneously engraved into the surface of the printing cylinder. For example, such a lane contains one or more entire magazine pages. One problem that thereby arises is that cups having different volumes are generated in the individual lanes given the same tone value to be engraved, this occurring because of the different engraving systems that are driven independently of one another and leading to differences in the individual lanes that the eye detects during later observation. For this reason, for example in packaging printing, only one engraving system is employed so that these errors, which are tolerated in magazine printing, do not occur.

When engraving the cups, the cup volume is varied dependent on the image content of the master to be printed. The respective tone value of the master should thereby be reproduced exactly as possible during printing. When scanning the masters, the analog-to-digital converters having, for example, a resolution of 12 bits are utilized for recognizing the tone value gradations for reasons of image signal processing (for example, gradation settings), this corresponding to a resolution of 4096 tone values in this case. The signal for the drive of the electromagnetic engraving system is acquired from [these]<u>this</u> high-resolution image information, said signal usually being an 8-bit signal[, this] corresponding to a resolution into 256 tone value gradations. In order to generate the corresponding volumes that are required for achieving this scope of gradations, the penetration depth of the diamond stylus into the copper surface is varied with the drive of the magnet system, whereby the geometry of the cups changes between approximately 120 μm diameter given a depth of 40 μm and approximately 30 μm diameter given a depth of 3 μm. Because only an extremely small range of variation in the depth of the cups between 40 μm and 3μm is available, the penetration depth of the stylus with which the cups are engraved must be exactly driven to fractions of a μm in order to reproducibly achieve the desired range of gradation. As can be seen therefrom, an extremely high precision is required in the engraving of the cups, at least as regard <u>to</u> the generation of the

required diameters and depths of the cups. Since the geometry of the engraved cups is directly dependent on the shape of the stylus, extremely high demands are also made of the geometry of the diamond stylus which, as has been shown, can only be achieved with extremely high [outlay]expense and with a high rejection rate in the manufacture of the stylii. Moreover, the diamond stylus is subject to wear since, when engraving a large printing cylinder having fourteen lanes, a circumference of 1.8m and a length of 3.6m given a screen of 70 lines/cm - which corresponds to a plurality of 4900 cups/cm^2, a stylus must engrave approximately 20 million cups. When one of the diamond stylii breaks off during the engraving of a printing cylinder, then the entire printing cylinder is unuseable[; o]. On the one hand, this causes a considerable financial loss and, on the other hand, represents a serious loss of time since a new cylinder must be engraved, postponing the start of printing by hours. For this reason, users frequently replace stylii earlier than necessary. As can also be seen therefrom, the endurance of the diamond stylii is also a critical concern.

All in all, electromagnetic engraving is well-suited for producing high-quality rotogravure cylinders; however, it has a number of weak points and is extremely complicated and one would like to eliminate these disadvantages with a different method.

The cups produced in this way, which are intended to accept the ink later, are also arranged on the surface of the printing form in conformity with a fine, regular screen, namely the printing screen, whereby a separate printing cylinder is produced for each ink, and whereby a different screen having a different angle and different screen width is respectively employed. [G]When printing in the printing press, given these screens, narrow webs remain between the individual cups, these supporting the doctor [when printing in the printing press]blade that removes the [access]excess ink after the inking. Another disadvantage of this operating mode of this electromechanical engraving is that texts and lines must also be reproduced [rastered]in screened fashion, which leads to step-patterns in the contours of the written characters and the lines that the eye perceives as being disturbing. This is

one advantage compared to the widespread offset printing wherein this stepping can be kept [in]an order of magnitude lower, which can then no longer be perceived by the eye, and [leading]which leads to a better quality that rotogravure could hitherto not achieve. This is a serious disadvantage of the rotogravure process.

In rotogravure, no stochastic screens can be generated wherein the size of the cups and the position of the cups can be randomly distributed corresponding to the tone value; this[, however,] is not possible when engraving with the diamond stylus. Such stochastic screens are also frequently referred to as "frequency-modulated screens" that have the advantage that details can be reproduced far better [and that]with no Moirè, this also leading to a better image quality than in rotogravure.

It is also known to utilize the electron beam engraving method applied in the processing of materials for generating the cups, this having exhibited extremely good results because of the high energy of the electron beam and the incredible precision with respect to the beam deflection and beam geometry.

This method is described in the publication, "Schnelles Elektronenstrahlgravierverfahren zur Grvur von Metallzylindern", Optik 77, No. 2 (1987) pages 83-92, Wissenschaftliche Verlagsgesellschaft mbH Stuttgart. Due to the extremely high [outlay]expense that is required for the hardware and electronics, electron beam engraving has hitherto not prevailed in practice for the engraving of copper cylinders for rotogravure but only in the steel industry for surface engraving of what are referred to as textured drums for sheet metal manufacture wherein textures are rolled into the sheets.

It has been repeatedly proposed in the trade literature as well as in the patent literature to engrave copper cylinders with lasers. Since copper, however, is an extremely good reflector for laser radiation, extremely high powers and, in particular, extremely high power densities of the lasers to be employed are required in order to penetrate into the copper and melted. There has hitherto not been any laser engraving unit with laser radiation sources having a

correspondingly high powered density and energy with which one succeeds in providing the copper cylinders for rotogravure with the required cup structure in the copper surface.

Attempts have nonetheless been made to utilize lasers for rotogravure in that a switch has been made to materials other than copper. Thus, for example, the publication DE-A-19 20 323 has proposed to prepare copper cylinders [such]with chemical etching such that the surface of the copper cylinder already comprises cups that have a volume that corresponds to the maximum printing density. These cups are filled with a solid filler material, for example plastic. [As m]Much of the filler material is then removed with a laser until the desired cup volume has been achieved. This method in fact manages with a lower laser power than would be necessary in order to melt and evaporate the copper as in electron beam engraving. In this method, however, the remaining plastic is attacked by the solvent of the ink in the printing process and is decomposed, so that only a low print run is possible. This method has not proven itself in practice and has thus not been utilized.

The publication of the VDD Seminar Series, "Direktes Lasergravierverfahren für metallbeschichtete Tiefdruckzylinder", published within the framework of a "Kolloquium vom Verein Deutscher Druckingenieure e.V. und dem fachgebiet Druckmaschinen und Druckverfahren, Fachbereich Maschinenbau, technische Hochschule Darmstadt", by Dr. phil. Nat. Jakob Frauchiger, MDC Max Dätwyler, AG, Darmstadt, 12 December 1996, has proposed that rotogravure cylinders plated with zinc be engraved by a quality-switched Nd:YAG high-power solid-state laser pumped with arc lamps. In this method, the volume of the cups is defined by the optical power of the laser. The laser power required for the engraving is transmitted onto the cylinder surface via an optical fiber whose output is imaged onto the cylinder surface through a variable focusing optics. One disadvantage of this method is that the arc lamps required for pumping the laser have a relatively short service life and must be replaced after approximately 500 hours of operation. The engraving cylinder

becomes unuseable given a failure of the pump light source during the engraving. This corresponds to a failure of the diamond stylus in electromechanical engraving and results in the same disadvantages. A preventative replacement of the arc lamps is cost-intensive and work-intensive, particularly since one must count on the fact that the laser beam must be re-adjusted in position after the replacement of the lamps. These lamp-pumped solid-state lasers also have a very poor efficiency since the laser-active material absorbs only a slight fraction of the available energy from the pump source, i.e. from the arc lamp here, and converts into laser light. Particularly given high laser powers, this means a high electrical connection [value]cost, high operating costs for electrical energy and cooling and, in particular, a considerable [outlay]expense for structural measures due to the size of the laser and the cooling unit. The space requirements are so high that the laser unit must be located outside the machine for space reasons, this in turn [be]being accompanied by problems in bringing the laser output onto the surface of the printing cylinder.

A critical disadvantage of this method is [comprised therein]that zinc is significantly softer than copper and is not suitable as a surface material for printing cylinders. Since the doctor blade with which the excess ink is removed before printing in the printing press is a steel blade, the zinc surface is damaged after a certain time and the printing cylinder becomes unuseable. A printing cylinder having a surface of zinc therefore does not even begin to approach as long a service life in printing as a printing cylinder having a surface of copper. Printing forms having a zinc surface are therefore not suitable for high press runs.

Even if the zinc surface is chrome-plated after the engraving, as has been also proposed [-]in order to lengthen the service life, the durability does not come close to that of normal copper cylinders. Chrome does not adhere to zinc as well as it adheres to copper and what is referred to as "hot chrome plating", which is successfully employed given copper cylinders in order to achieve an optimum adhesion of the chromium on the copper, is not possible given zinc since the zinc would thereby melt. Since the chrome layer does not adhere very well on the

zinc, it is likewise attacked by the doctor blade, which leads to a relatively early failure of the printing cylinders. When, in contrast thereto, copper cylinders are chrome-plated according to this method, then incredibly high press runs are possible since the chromium firmly adheres on the copper surface, so that these copper cylinders out perform the chrome-plate zinc cylinders by far.

It proceeds from the publication EP-B-0 473 973, which is likewise directed to the method described above, that an energy of 6 mWsec is required in this method given zinc for cutting a cup having a diameter of 120 µm and a depth of 30 µm. An energy of 165 mWsec is recited in this publication for copper, this amounting to a factor of 27.5 for the required laser power. Lasers having a continuous-wave performance of several kilowatts given good beam quality are thus required in order to produce cups in copper with a speed that is accessible for the printing industry. Such a power, however, cannot be produced with the laser arrangement described above. For this reason, it is likewise only possible to engrave a zinc surface.

Such a laser arrangement, which is composed of a single solid-state laser, in fact makes it possible to process rotogravure cylinders having a zinc surface; if, however, one wishes to utilize the advantages of the copper surface and stay with copper cylinders and engrave these with a laser, the high power density required for penetration into the surface of the copper and the high energy required for melting the copper must be inevitably exerted. This, however, has not hitherto been successfully done with a solid-state laser.

It is known that the beam quality in solid-state lasers, i.e. the focusability, decreases with increasing power. Even if the power of the solid-state lasers were to be driven up or if a plurality of solid-state lasers were directed onto the same cup or parts thereof, it would therefore not be possible to satisfactorily engrave copper cylinders for rotogravure with such a laser because the precision of the laser beam, as offered by the electron beam, required for generating the fine structures cannot be achieved. If the laser power were increased given this apparatus, then a further problem would arise: the focusing of high radiant

intensity in optical fibers is, as known, difficult. The fibers burn at high power as a consequence of m[al]isadjustment at the infeed location. If one wishes to avoid this, however, the fiber diameter would have to be enlarged which, however, in turn has the disadvantage that the fiber diameter would have to be imaged onto the processing page[[sic]] with even greater demagnification. A demagnified imaging, however, leads to an increase in the numerical aperture on the processing page and, consequently, to a reduced depth of field on the processing surface. As proposed, the distance from the processing surface could be kept constant. When, however, the beam penetrates into the surface of the material, then a defocussing automatically derives. This [having]has a disadvantageous influence on the required power density and on the exact dot size. Since, however, the diameter of the processing spot and the energy of the beam determine the size of the cup, it then becomes difficult to make the cup size exactly as required by the desired tone value. [To]For this [end]purpose, it would also be necessary that the laser power is exactly constant and also remains constant over the entire time that is required for a cylinder engraving. When this is not the case, the cup size changes and the cylinder becomes unuseable. This cannot be compensated by varying the size of the processing spot since it is not possible to adequately vary the processing spot in shape.

Further, a complicated modulator is required given such an arrangement. As known, modulators for extremely high laser powers are slow, this leading to a reduction of the modulation frequency and, thus, of the engraving frequency. When, however, the engraving frequency is too low, the energy diffuses into the environment of the processing spot on the processing surface without cutting out a cup. It is therefore necessary to also exert a high power in addition to the high energy for the cutting.

The publication "Der Laser in der Druckindustrie", by Werner Hülsbuch, page 540, Verlag W. Hülsbusch, Constanc, describes that it is particularly a matter of a high powered density in processing materials given power densities of typically above 10^7 through 10^8 W/cm^2, a spontaneous evaporation of the material

occurs in all materials, this being accompanied by a sudden absorption rise, which is especially advantageous since the laser power is then no longer reflected from the metal surface. When, for example, a laser source of 100 W is available, then the processing spot dare not be larger than 10 μm in order to arrive at these values in the region, as proceeds from the following equation: 100 W : (0.001 cm x 0.001 cm)=10^8 W/cm^2.

SUMMARY OF THE INVENTION

[An]One object of the present invention is to improve a laser radiation source, preferably for processing materials, as well as an arrangement for processing materials having a laser radiation source and the operation thereof such that an extremely high power density and energy are achieved in a cost-beneficial way, and such that both the beam shape with respect to flexibility, precision and beam positioning as well as the beam power can be exactly controlled even given significantly higher laser powers.

[This object is achieved by the features of claims 1 through 27 with respect to the]

According to the present invention, a laser radiation source[.

Advantageous] is provided for generating laser beams with high power density and higher energy for processing material. A plurality of directly modulatable, diode-pump fiber lasers are provided having outputs arranged in a first ordering pattern. An optical unit is provided connected to the outputs of the fiber lasers wherein laser beams emerging from the outputs of the individual fiber lasers are shaped and aligned such that they impinge onto a processing surface in a second ordering pattern.

Further advantageous developments and improvements with respect to the apparatus for processing materials with the laser beam source and the operation thereof are [recited in the subclaims]discussed hereafter.

This laser radiation source [is composed of]comprises a plurality of diode-pumped fiber lasers whose output radiation beams impinge the processing location next to one another and/or over one another or in a point or bundle and

thus enables the generation of a processing spot that is designationally variable in shape and size, even given extremely high laser powers and extremely high power densities. According to the invention, these fiber lasers can be implemented as continuous wave lasers or as quality-switched lasers, also referred to as Q-switch lasers, whereby they are advantageously internally or externally modulated and/or comprise an additional modulator. Q-switch lasers have an optical modulator available to them within the laser resonator, for example an acousto-optical modulator, that, in its opened condition, interrupts the laser effect given a pump radiation that continues to exist. As a result thereof, energy is stored within the laser resonator, this being output as a short laser pulse having high power when the modulator is closed in response to a control signal. Q-switch lasers have the advantage that they emit short pulses having high power, which briefly leads to a high power density. An advantageous elimination of the molten and evaporated material is enabled in the pulsed mode due to the brief-term interruptions in the processing event. Instead of switching the quality, a pulsed mode can also be generated with internal or external modulation.

The processing spot can be designationally modified in shape and size in that different [pluralities]<u>numbers</u> of[the] lasers[that] are provided<u> that</u> can be switched on for shaping the processing spot. It is thereby especially advantageous that the depth of the cut cup can be determined by the laser energy independently of its shape and size. Further, a control of the energy of the individual lasers can also generate any arbitrary beam profile within the processing spot and, thus, any arbitrary profile within the cup as well.

Further advantages of the present invention compared to known laser radiation sources are comprised therein that the infeed of the radiant power from a solid-state laser into an optical fiber can be eliminated but the exit of the fiber laser supplies diffraction-limited radiation that, according to the invention, can be focused onto less than a 10 μm diameter, as a result whereof an extremely high power density is achieved given the greatest possible depth of field.

Given a traditional arrangement with solid-state lasers, the size of the processing spot lies in the region of approximately 100 μm. Given the present invention, thus[,] a power density that is improved by the factor 100 derives, and a design possibility in the area of the processing spot that is improved by the factor 100 derives.

Due to the high precision and due to the processing spot that can be designed in very fine fashion, extremely fine screens, also including the stochastic screens that are also called frequency-modulated screens (FM screens) and, thus[,] extremely smooth edges in lines and written characters can be economically produced, so that rotogravure no longer need be inferior to offset printing in terms of printing quality.

Due to the operating mode of the [inventive]laser radiation source<u> of the invention</u>, it is also possible to link arbitrary raster widths to arbitrary screen angles and apply arbitrary different screen widths and arbitrary different screen angles at arbitrary locations on the same printing cylinder. Line patterns and text can also be applied independently of the printing screen as long as one sees to sufficient supporting locations for the doctor blade.

One advantage of the invention is [comprised therein]that the differences in the data editing for the production of the printing form are reduced to a minimum between rotogravure and offset printing, this yielding substantial cost and time savings. Up to now, the data for the rotogravure are acquired by conversion from the data already present for the offset printing because a signal is required for the drive of the engraving system that defines the volume of a cup, whereby the area of a screen dot is determined in offset printing. As a result of the multiple arrangement of lasers, the [inventive]laser beam source<u> of the invention</u> makes it possible to vary the area of a cup given constant depth, for which reason it is no longer required to convert the data for offset printing into data for the rotogravure. The data for the offset printing can be directly employed for engraving the rotogravure forms.

Another advantage of the invention is [comprised therein is]that both the area of a cup as well as the depth can be controlled independently of one another with this laser beam source, this leading [thereto]to that a greater [plurality]number of tone value gradations that can be reproducibly generated, this leading to a more stable manufacturing process for the printing cylinders and to an improved printing result.

It is also a critical advantage that the energy can be unproblemmatically transported from the pump source to the processing point with the fiber, namely the fiber laser itself, or with a fiber that is welded on or, respectively, attached in some other way, this yielding an especially simple and space-saving structure.

Another advantage of the invention is [comprised therein]that the efficiency of such an arrangement with fiber lasers is significantly higher than the efficiency of solid-state lasers, since absorption efficiencies of more than 60% are achieved for fiber lasers, these lying only at approximately half given traditional dialed-pumped solid-state lasers and being even far lower given lamp-pumped solid-state lasers. Given the required power of several kilowatts for an efficient engraving of rotogravure cylinders, the efficiency of the lasers is of incredible significance for the system costs and the operating costs.

Further, a multiple arrangement of lasers yields the advantage that the outage of a laser is less critical than given a single-channel arrangement. When the only laser that is present given the single-channel arrangement fails during the engraving of a printing cylinder, the entire printing cylinder is unuseable. When, however, a laser fails given a multiple arrangement, then the power of the remaining lasers can, for example, be slightly boosted in order to compensate the failure. After the end of the engraving, the laser that has failed can then be replaced.

The dissertation, “Leistungsskalierung von Faserlasern”, Physics Department of the University of Hannover, Dipl.-Phys. Holger Zellmer 20 June 1996, fiber lasers are discussed as being known. These lasers, however, had already been proposed by Snitzer and Köster, without these having been

previously utilized for processing materials given high powers. Although powers of up to 100 W can be fundamentally achieved with the lasers described in this dissertation, no useable arrangements are known for utilizing these lasers for purposes of the present invention.

The publication WO-A-95/16294 has already disclosed phase-coupled fiber lasers; however, these are extremely involved in terms of manufacture and are not suitable for industrial employment. It had hitherto not been recognized to bring lasers of this simple type to high power density and energy in the proposed, simple way and to utilize them for erosive processing of materials.

For example, the resonator length of the individual lasers must be kept exactly constant to the fraction of a micrometer, [to]for which [end]purpose what are referred to as "piezoelectric fiber stretchers" are utilized. As a result of the complex structure, it is likewise not possible to construct the laser unit modularly, i.e. of components that are simple to assemble and to be multiply employed or to replace individual laser components as needed on site as a consequence of the great [plurality]number of optical components within a phase-coupled laser[, m]. Moreover, the optical losses are extremely high, and the pump radiation absorption of the laser-active medium is low, which results in a low efficiency of the arrangement. Although fiber lasers are not particularly susceptible to back-reflections in and of themselves, phase-coupled lasers exhibit a great sensitivity to back-reflections due to their very principle, i.e. when portions of the emitted radiation proceed back into the laser resonator due to reflection or dispersion, as is unavoidable when processing materials. These back-reflections lead to uncontrolled output amplitudes and cause the laser to shut down. Although what are referred to as optical isolators are known, these being intended to attenuate such back-reflections, these involve a number of disadvantages in practice, which, for example, include the optical losses, the high price and the inadequate attenuation properties. The lasers for the [inventive] purpose of the invention of processing materials need not only exhibit a high power density but also must be

able to supply the required energy for cutting out the cups, must be extremely stable in terms of the emitted radiation and must have a very good efficiency.

Further, US-A-5,694,408 has disclosed a laser system wherein a master oscillator generates low-power radiation energy at a specific wavelength, this being optically intensified and it being distributed for further post-amplification onto a plurality of post-amplifiers, in order to then be in turn united to form a common beam, a precise phase readjustment of the individual post-amplified signals being required for this purpose in order to avoid interferences in the output signal. This requires complicated measuring and control procedures and involved actuating elements, for which [end]purpose, for example, electro-optical phase modulators must be utilized, these being extremely expensive and having to be operated with extremely high voltages.

Further, US-A-5,084,882 discloses a phase-coupled laser system that employs a plurality of fibers or[, respectively,] fiber cores in a bundle, the core thereof being, on the one hand, large compared to its cladding or[, respectively,] its spacing in order to achieve the phase coupling; on the other hand, this should only have a diameter of a few micrometers since it is a matter of single-mode fibers. This system is mainly provided as an optical intensifier.

Another phase-coupled laser system that is likewise implemented in an extremely complex way and that is composed of a plurality of what are referred to as "sub-oscillators" is disclosed by GB-A-21 54 364 under the title "Laser Assemblies", having already been disclosed in 1984; however, no industrial realizations with such phase-coupled laser systems have become known up to now.

It has also not been previously proposed to combine a [plurality]number of the initially cited fiber lasers in a simple way, i.e. without a complex phase coupling or the like, to form a compact, rugged and service-friendly radiation source for processing materials and, for example, to employ this for multi-track recording. An inventive, multiple arrangement of such simple lasers that can be cost-beneficially manufactured in quantity in several tracks and levels yields

enormous advantages for the purposes of the invention that would certainly not have escaped attention if the invention solution had been known.

A further advantage of fiber lasers is there clearly lower tendency to oscillate when energy proceeds back into the laser. Compared to traditional solid-state lasers, fiber lasers have a resonance overshooting that is lower by an order of magnitude in terms of its transfer function, this having been very positively proven during operation. When processing materials, namely, one cannot always prevent energy from being reflected from the processing location back into the laser because the melting material is explosively hurled in unpredictable directions and thereby flies through the laser beam before it can be removed and neutralized by particular [measures]<u>techniques</u> that are presented in one embodiment of the invention.

A critical advantage of the multiple arrangement of fiber lasers without phase coupling is [comprised therein]that the individual lasers behave differently in case of a back-reflection. This is related to the fact that, for example, some of the lasers are not affected at all by a back-reflection and others may possibly be effected only with a delay. The probability is therefore high that oscillations of the individual lasers, if they occur at all, are superimposed such that they have no negative influence on the quality of the results of the engraving.

The [inventive] laser radiation source<u> of the invention</u> can also be advantageously utilized for all other types of processing materials or transferring materials wherein high power density, high energy and great precision or, too, high optical resolution are important. In addition to engraving rotogravure cylinders having a copper surface, other materials such as, for example, all metals, ceramic, glass, semiconductor materials, rubber or plastics can be processed and/or materials can be stripped<u> from</u> more specifically prepared carrier materials and transferred onto other materials at high speed and with high precision. In addition to those that are uncoated, moreover, rotogravure cylinders, printing plates or printing cylinders that are coated with masks as well as all types of printing forms can also be produced or, respectively, processed at high speed and

with high resolution for offset printing, letter press printing, silk screening, flexo-printing and all other printing processes. For example, the offset printing plates having metal coating (bi-metal plates) that are employed for printing extremely large print runs in offset printing and similar materials can be provided with images in an environmentally friendly way, this having been hitherto possible only with etching.

Further, materials can be processed that contain a magnetizable surface, in that the parts of the material magnetized in large-area fashion by a pre-magnetization process are de-magnetized by briefly heating selected processing points to temperatures that lie above the Curie point, [being]when heated with the inventive laser radiation source. The material provided with images in this way for applications in printing technology can serve as a print master in conjunction with a corresponding toner.

As a result of the high power density of the inventive laser radiation source, it is also possible to directly process chromium. Thus, for example, printing cylinders of copper can already be chrome-plated for rotogravure before the laser engraving, this eliminating a work step after the engraving and benefitting the timeliness. Since the printout behavior of a cup engraved in copper is also better than that of a chrome-plated cup and its volume is more precise, this method also yields even better printing results in addition to the high service life as a result of the remaining chromium layer and the improved timeliness.

The employment of the inventive laser radiation source, however, is not limited to employments in printing technology but can be utilized anywhere that it is important to erode material or change the properties of the material by energy irradiation with lasers given high resolution and high speed. Thus, for example, the aforementioned texture drums can also be produced with the inventive laser radiation source. Further, the patterns of interconnects for printed circuit boards, including the boards for the components, preferably for multi-layer printed circuit boards, can be produced by eroding the copper laminate and allowing the

interconnects to stand, and by eroding copper laminate and carriers at the locations of the bores. Further, the surface structure of material surfaces can be partially modified by partial heating. For example, extremely fine structures having the hardness of material surfaces can be produced in large-area fashion in this way, this being particularly advantageous for bearing surfaces since the bearing properties can be intentionally influenced in this way. Further, there are non-conductive ceramic materials at whose surface metal crystallizes out due to energy irradiation, this being capable of being utilized in conjunction with the inventive laser radiation source for applications that require a high resolution, for example for producing interconnects.

The laser beams can thereby be guided to the processing spot in the greatest variety of ways and can be moved across the material; for example, the material to be processed can be located on a rotating drum past which the radiation source is conducted in relative fashion. However, the material can also be located in a plane over which the laser radiation source or its output radiation is conducted past in relative fashion. In a flat bed arrangement as presented in the aforementioned publication "Der Laser in der Druckindustrie" von W. Hülsbusch, Figure 7-28 on page 431 and as likewise disclosed in the publication EP-A-0 041 241, the radiation source presented therein as argon or He Ne laser or, respectively, as laser light source (4) in Figure 3 of the publication can be replaced by the inventive laser radiation source in order to utilize the advantages of the inventive laser radiation source. Further, the material to be processed can be located within a hollow cylinder over which the laser radiation source or its output radiation sweeps in a relative motion.

Inventively, the output of the laser radiation source can also be implemented with a variable [plurality]number of tracks whose mutual spacings are variable, preferably similar to a long comb, this moving relative to the material to be provided with images. Such an arrangement is disclosed by US-A-5,430,816. It is disclosed therein to direct the radiation of an excimer laser having a strength of approximately 50 watts onto a bundle of what are referred to as

stepped index fibers having diameters of 50 through 800 micrometers and to respectively couple a part of the radiation into the individual fibers. The exit of each fiber is then imaged onto the workpiece via a respective positive lens having a diameter of 60 mm, whereby the spacing between the individual processing points must amount to at least 60 mm and a protective mechanism to prevent contamination is required per positive lens. What is disadvantageous is that only a fraction of the laser energy thus proceeds into the respective fibers[, t]. The energy distribution turns out very differently and changes in the exit power derive given movement of the fibers, for which reason what are referred to as scramblers must be utilized in order to avoid this[; t]. These scramblers, however, disadvantageously influence the efficiency of the system and increase the costs. Only relatively imprecise bores having a diameter of approximately 130 micrometers can be produced in plastic with such an arrangement. The pulse rate of the laser is the same for all simultaneously produced bores, so that all bores must be implemented of the same size. Moreover, the system is relatively slow since a boring processing lies between one and two seconds. An arrangement having fiber lasers yields tremendous advantages compared thereto[;]: the speed can be increased by several orders of magnitude and metals can also be processed; the precision is substantially greater since fiber lasers also exhibit a stable output power given movement of the laser fibers; and bores having diameters below 10 micrometers can also be unproblemmatically produced. Since each fiber laser can be separately modulated, different processing patterns are possible. Further, the end sections of the fiber lasers can be unproblemmatically implemented smaller than 2.5 mm in diameter, this enabling a clearly smaller spacing between the processing tracks. As a result thereof, it is also possible to employ a shared protective mechanism to prevent contamination of the optics.

Another example for the application of the inventive laser beam source wherein the material is preferably arranged in a plane derives in the semiconductor industry in the processing of what are referred to as wafers, i.e. usually circular disks of suitable semiconductor material that, for example, are

incised or cut or can be provided with all conceivable patterns in the surface, of a type that could previously be manufactured only by time-consuming chemical etching processes that were also not environmentally friendly.

For the multi-channel cutting and in sizing of materials, a simplified embodiment of the laser radiation source is inventively possible, as disclosed in the German Patent Application P 198 40 936.2 of the assignee, "Anordnung zum mehrkanaligen Schneiden und Ritzen von Materialien mittels Laserstrahlen".

A further inventive application of the laser radiation source is established in the manufacture of monitors and displays. For example, the apertured masks for color picture screens as well as the masks of what are referred to as flat picture screens or LCD displays can be manufactured in a more environmentally friendly way with laser processing than with the chemical etching processes that were previously employed, in that the inventive laser radiation source is applied.

A considerable advantage of the inventive laser radiation source is that it has a small volume and has a flexible connection, namely the laser fibers or fibers connected thereto between the pump source and the exit of the radiation at the processing location and thus allows all conceivable operating positions of the laser radiation source or of its beam exit. There are therefore also no limitations for the spatial arrangement of the processing surface, since they can be arranged in an arbitrary attitude in space.

Another advantage of the invention is comprised therein that the radiation beam of the individual lasers with defined values in beam diameter, beam divergence centering and angular direction can be exactly and durably acquired in a terminating section (terminator), as a result whereof a fabrication-suited and service-suited arrangement for forwarding the laser radiation onto the processing surface can be created. Inventively, the radiation beams can thereby be coupled into the fiber dependent on the application, for example as pump spot and/or can be coupled out as parallel laser beam, can diverge at the exit location or, for example, can be focused in a certain distance from the exit point. There is [thereby]<u>thus</u> a desire to fashion the terminator as small as possible and to provide

it with one or more fits as a reference surface or reference surfaces for the alignment of the laser beam.

According to the invention, this is achieved in that the optical fibers are set in the terminator and the position of the optical fibers and/or the position of the emerging radiation beam is exactly adjusted. On the basis of the exact adjustment and of an inventive, correspondingly spatially small embodiment of the terminators which can also be attached to one another in an especially simple way as a result of a special shaping, it becomes possible to combine the radiation beams of a plurality of fiber lasers and focus them such that the respectively encountered object is achieved and, at the same time, an economical manufacture as well as a cost-beneficial maintenance of the laser radiation source is enabled.

The invention is explained in greater detail below on the basis of Figures 1 through 44a.

[Shown are]BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1[ ] is a schematic illustration of the laser radiation source;

Fig. 2[ ] is a fundamental illustration of the fiber laser (prior art);

Fig. 2a[ ] is an attenuated illustration of the fiber of the fiber laser (prior art);

Fig. 3[ ] is a cross-section through an arrangement for processing material with [an inventive]a laser radiation source of the invention;

Fig. 4[ ] is an illustration of a laser gun for the inventive laser radiation[ ] source having a multiple arrangement of fiber lasers;

Fig. 4a[ ] is a perspective illustration relating to Fig. 4;

Fig. 4b[ ] is a version of Fig. 4;

Fig. 4c[ ] is a further version of Figs. 4 and 4b;

Fig. 5[ ] is an example of a terminator for the outfeed of the radiation from a fiber or, respectively, from the fibers of a fiber laser;

Fig. 5a[ ] is an example of a multiple arrangement for a plurality of terminators;

Fig. 5b[ ] is an example of a terminator having adjustment screws;

Fig. 5c[ ] is a cross-section through the terminator according to Fig. 5b in the region of the adjustment screws;

Fig. 6 [ ]is an example of a terminator having spherical adjustment[ ]

elements;

Fig. 6a[ ] is a cross-section through the terminator according to Fig. 6 in the region of the spherical adjustment elements;

Fig. 7[ ] is an example of an embodiment of a terminator having a conical fit for insertion into a mount;

Fig. 8 [ ]is an example of a multiple mount for a plurality of terminators;

Fig. 8a[ ] shows the rear fastening of the terminators according to Fig. 8;

Fig. 9 [ ]is an example of an embodiment having quadratic cross-section;

Fig. 9a[ ] is a cross-section through the terminator according to Fig. 9;

Fig. 10[ ] is an example of a terminator having rectangular cross-section and a trapezoidal plan view;

Fig. 10a[ ] is a longitudinal section through the terminator according to Fig. 10;

Fig. 10b[ ] is a cross-section through the terminator according to Fig. 10;

Fig. 11[ ] is an example of a terminator having trapezoidal cross-section;

Fig. 11a[ ] is an example of a terminator having triangular cross-section;

Fig. 12[ ] is an example of a terminator having honeycomb-shaped cross-section;

Fig. 13[ ] is a modular implementation of the fibers of the fiber laser according to Fig. 1;

Fig. 14[ ] is an example of the infeed of the pump energy into the fibers of the fiber laser according to Fig. 13;

Fig. 15[ ] is an example of a fiber laser having two outputs;

Fig. 16[ ] is an example of the merging of two fiber lasers;

Fig. 17[ ] is a schematic illustration of the beam path through an acousto-optical deflector or, respectively, modulators;

Fig. 18 shows blanking out unwanted sub-beams of an acousto-optical[ ] deflector or, respectively, modulators;

Fig. 18a[ ] is an arrangement having an electro-optical modulator;

Fig. 19[ ] is a plan view onto a four-channel acousto-optical modulator;

Fig. 19a[ ] is a section through the modulator according to Fig. 19;

Fig. 20[ ] is a schematic beam path for a plan view for Fig. 4;

Fig. 21[ ] is a schematic beam path for a plan view for Fig. 4b;

Fig. 22[ ] is a schematic beam path for a plan view for Fig. 4c;

Fig. 23 shows a beam path for terminators that are arranged at an angle[ ] relative to one another;

Fig. 24[ ] is a version of Fig. 23 that contains a multi-channel acousto-optical modulator;

Fig. 24a[ ] is a version for Fig. 24;

Fig. 25[ ] is an intermediate image for matching the fiber lasers or, respectively, their terminators to, for example, the modulator;

Fig. 26 shows the merging of twice for tracks of the beam path from[ ] terminators with a strip mirror arrangement;

Fig. 26a[ ] is a plan view for Fig. 26;

Fig. 27[ ] is a view of a strip mirror;

Fig. 27a[ ] is a sectional drawing through the strip mirror according to Fig. 27;

Fig. 27b[ ] is another example of a strip mirror;

Fig. 28 shows the combining of twice for tracks of the ray beam from[ ] terminators with a wavelength-dependent mirror;

Fig. 28a[ ] is a plan view of Fig. 28;

Fig. 29[ ] is an arrangement of a plurality of terminators in a plurality of tracks and in a plurality of planes;

Fig. 30[ ] is an arrangement of a plurality of terminators in a bundle;

Fig. 31[ ] is a sectional view through the ray beam from the terminators of the fiber lasers F1 through F3 according to Fig. 29 or Fig. 30;

Fig. 32[ ] is an arrangement having a plurality of terminators in a plurality of tracks and a plurality of levels having a cylindrical optics for matching, for example, to the modulator;

Fig. 33[ ] is a modification of Fig. 32;

Fig. 34 shows a mouthpiece for the laser gun with connections for[ ] compressed air and for extracting the material released by the beam;

Fig. 35 shows a turning of the laser gun for setting the track spacings;

Fig. 36[ ] is an illustration for generating four tracks with an acousto-optical multiple deflector or[, respectively,] multiple modulator;

Fig. 36a[ ] is a spatial presentation of an acousto-optical multiple deflector or[, respectively,] multiple modulators;

Fig. 36b[ ] is an expanded embodiment related to Fig. 36a;

Fig. 36c[ ] is a plan view of Fig. 36b;

Fig. 37[ ] is an illustration for generating multiple tracks with the assistance of an acousto-optical multiple deflector or[, respectively,] multiple modulator;

Fig. 38[ ] is an advantageous arrangement for avoiding reflections back into the lasers;

Fig. 39[ ] shows a lens that has coolant flowing around it;

Fig. 39a[ ] is a section through a mount 4 an objective lens;

Fig. 40[ ] shows a fiber laser or a fiber that have been clearly reduced in cross-section at their exit end;

Fig. 40a[ ] is a plan view onto the end of the fiber laser or the fiber according to Fig. 40;

Fig. 40b[ ] is a side view of the fiber end wherein the axes of the emerging ray beams proceed nearly parallel;

Fig. 40c [ ] is a side view of the fiber end wherein the axes of the emerging ray beam overlap outside the fiber bundle;

Fig. 40d[ ] is a side view of the fiber end wherein the axes of the emerging ray beams overlap within the fiber bundle;

Fig. 41[ ] shows an arrangement of fiber lasers or fibers according to Fig. 40 in a plurality of tracks and levels;

Fig. 42[ ] shows a f[a]urther embodiment of the laser radiation source;

Fig. 42a[ ] shows a [farther-reaching]further embodiment according to Fig. 42;

Fig. 42b[ ] is a sectional view of Fig. 42a;

Fig. 42c[ ] is an illustration of a robot;

Fig. 43[ ] shows a flat bed arrangement having the inventive laser beam source;

Fig. 43a[ ] is an addition to Fig. 43;

Fig. 43b[ ] is a sectional drawing through an arrangement for removing the material released during the processing;

Fig. 44[ ] is a hollow bed arrangement having the inventive laser beam source; and

Fig. 44a[ ] shows an addition to Fig. 44.

DESCRIPTION OF THE PREFERRED EMBODIMENT

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the preferred embodiment illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is there3by intended, such alterations and further modifications in the illustrated device, and such further applications of the principles of the invention as illustrated therein being contemplated as would normally occur to one skilled in the art to which the invention relates.

Fig. 1 shows a laser radiation source 1 that is composed of a plurality of diode-pumped fiber lasers [(]2[)], also called fiber lasers, inventively implemented preferably as modules, these being charged with electrical energy by a preferably modular supply 32 that is largely converted into laser radiation. Further, a controller 33 is provided via which the modulation of the radiation is undertaken and that [cease]sees to the interaction of the laser radiation source with its periphery. The output rays of the laser enter into an optical unit 8 at the radiation entry 9 and emerge from the optical unit at the radiation exit 10. The job of the optical unit 8 is to shape the laser radiation to form a processing spot 24 on a processing surface 81; however, the laser radiation can also be directly directed on to the processing surface without the optical unit.

Figs. 2 and 2a show the fundamental structure of a fiber laser arrangement [(]2[)]. In Fig. 2, the energy of a pump source such as, for example, a laser diode, called a pump source 18 here, is shaped via an infeed optics 3 to form a suitable pump spot 4 and is coupled in to the laser fiber 5. Such pump sources are disclosed, for example, in German Patent Application P 196 03 704 of the assignee. Typical pump cross-sections of the laser fibers lie approximately between 100 μm and 600 μm in diameter given a numerical aperture of

approximately 0.4. The laser fiber 5 is provided with an infeed mirror 7 at the infeed side 6 that allows the pump radiation to pass unimpeded but which exhibits 100% reflection for the laser radiation. The infeed mirror 7 can be secured to the fiber end with a suitable mount or by gluing; however, it can also be realized on the fiber end by direct vapor-deposition of a suitable layer as employed given infeed mirrors for lasers. An outfeed mirror 12 that is partially reflective for the laser radiation is attached to the outfeed side 11 of the laser fiber 5, the laser radiation 13 being coupled out through [said]the outfeed mirror 12. Advantageously, the outfeed mirror exhibits 100% reflection for the pump radiation. As a result thereof, the remaining pump radiation is reflected back into the optical fiber, which is advantageous since the pump energy is utilized better and, further, does not represent a disturbing factor in the application of the laser radiation. The outfeed mirror can, like the infeed mirror, likewise be produced by vapor-deposition.

The infeed event of the pump radiation into the pump cross-section 14 of the laser fiber 5 is shown in greater detail in Fig. 2a. The energy in the pump spot 4 excites the laser radiation in the core 15 of the laser fiber 5 on its way through the fiber. The pump core 16 is surrounded by a cladding 17. The core of the laser fiber that is approximately 5 μm through 10 μm thick is doped mainly with rare earths.

The relatively large pump cross-section 14 simplifies the infeed of the pump energy and enables the use of a connection between pump source and laser fiber that is simple to release, as shown in Figs. 13 and 14. The terminator of the laser fiber at the side of the pump source can thereby be advantageously structurally the same as the terminator at the outfeed side; however, it need not be. A precise blood-type connection between pump source and laser fiber offers considerable advantages in the manufacture of the fiber laser and in case of service. The laser fiber, however, can also be firmly connected to the pump source to form a laser module. As a result of the intentionally manufactured,

extremely small fiber core diameter, the fiber laser supplies a practically diffraction-limited laser radiation 13 at the exit.

Fig. 3 shows a cross-section through one of the inventive embodiments of an arrangement for processing materials with the inventive laser radiation source [(]1[)]. A drum 22 is rotatably seated in a housing 21 and is placed into rotation by a drive (not shown). A laser gun 23, which is conducted along the drum in the axial direction with a carriage (not shown), is located on a prism (likewise not shown).

The laser radiation emerging from the laser gun 23 impinges the surface of the drum at the processing location in the processing spot 24. Either the surface of the drum as well as a material clamped onto the drum surface can be processed. The fiber lasers, whose laser fibers 5 are respectively wound to a form, for example, an air-permeated coil 25, are supplied into the laser gun 23 with the inventive terminators 26, 94. Advantageously, however, passive single-mode fibers or other passive optical fibers, [refer]referred to in brief as fibers 28, can also be welded to the fiber lasers or coupled thereto in some other way before the terminators 26, 94 are attached, as described in Figs. 15 and 16.

The pump sources 18 of the fiber lasers are attached on a cooling member 27 that diverts the waste heat via a cooling system 31. The cooling system 31 can be a matter of a heat exchanger that delivers the waste heat to the surrounding air; however, it can also be a matter of a cooling unit. The laser gun 23 can also be connected to the cooling system, but this is not shown. The driver electronics for the pump sources 18, which belong to the supply 32 (not shown in further detail), are preferably situated on the cooling member. A machine control is provided for the drives but is not shown in Fig. 3. The structure of the pump sources, fiber laser and [appertaining]corresponding power electronics is preferably modularly implemented, so that corresponding pump sources and power modules of the driver electronics that are separate or combined into groups belong to the individual fiber lasers, these being capable of being connected to one another via a bus system. As explained in greater detail in Fig. 13 and Fig. 14, the laser fibers 5

and the pump sources 18 can be connected to one another via a releasable connection. It is also possible to couple a slight part of the pump radiation out of the laser fiber 5, for example as a result of a slight injury to the cladding 14, and to conduct this via an optical fiber onto a measuring cell in order to offer a signal therefrom that can be employed for the control or, respectively, regulation of the pump radiation.

The modulation signals for the laser radiation are generated in the controller 33 and the interaction of the laser radiation source with the machine control and with the supply 32 as well as the executive sequence of the calibration events as well as of the control and regulation events are managed in [said]the controller 33. A safety circuit (not shown), for example, switches the pump sources permanently off when there is danger.

Although a horizontally seated drum is shown in Fig. 3, the drum [can be]being arranged in any arbitrary attitude since the inventive laser radiation source is completely directionally insensitive in terms of its attitude and is very compact in terms of structure and, moreover, since the laser fibers 5 of the fiber laser or fibers 28 coupled to the laser fibers can be arbitrarily laid; for example, the shaft of the drum can also be seated vertically or inclined from the perpendicular, which yields an especially small floor space. As a result thereof, moreover, the operation of a plurality of arrangements or a system having a plurality of drums is possible on the same floor space as would be required by an arrangement having a horizontally seated drum. As a result thereof, the printing forms can be manufactured faster; in particular, all printing forms for a color set can be produced in a single, parallel pass, which is advantageous especially with respect to the uniformity of the final result. Further, an automatic charging with printing forms for provision with images can be realized better given a system erected on a small floor space than given a spatially larger system. One or more laser radiation sources and, additionally, one or more further lasers can be directed onto the same printing form in order to accelerate the production thereof. One advantage of the multi-track arrangement having the very fine and precise tracks

is[thereby] that potential seams are clearly less disturbing then when recording is carried out with coarser tracks. As described under Fig. 37, further, the position of the tracks can be precisely re-adjusted, so that residual errors become clearly smaller than a track width. The inventive laser radiation sources can thereby be preferably utilized for processing the finer contours and the further laser or lasers can be utilized for processing rougher contours, which can be particularly employed given printing forms that, for example, are composed of plastic or rubber.

Instead of one or each of the provided fiber lasers 2, it is conceivable to provide a laser system with a terminator into [[sic]]the laser radiation source and alternative[ly] supply to the laser gun 23, whereby the fiber laser described in detail under Fig. 2, however, represents the more cost-beneficial solution. When processing materials, namely, if the radiant power of a plurality of lasers that are not coupled to one another and that naturally emit with a slight wavelength difference are directed onto a processing spot, a phase equality of the individual lasers can be foregone and an expensive control and regulation technology for a phase coupling that is susceptible to malfunction can be avoided.

Such a laser system that, for example, is disclosed by US-A-5,694,408 contains an optical post-amplification and comprises a radiation output composed of a fiber. A terminator is described in greater detail later in one of the Figures 5, 5a, 5b, 5c, 6, 6a, 7, 9, 9a, 10, 10a, 10b, 11, 11a or 12.

Instead of employing the laser system disclosed by US-A-5,694,408, it is also conceivable to employ a phase-coupled laser system according to US-A-5,084,882. An image of the fiber bundle then [derives]<u>results</u> on the processing surface as the respective processing spot. Alternatively, a single-mode fiber could be welded to each fiber at the exit of the bundle, this [could be]<u>being</u> provided with the respective terminators, and supply the laser gun. However, it is extremely difficult and complicated to manufacture such phase-coupled laser systems and they would be correspondingly expensive. Up to now, such phase-coupled laser systems have also not been commercially available.

Fig. 4 is a section through an applied example of a laser gun having sixteen fiber lasers that are coupled via terminators 26 and having a modulation unit composed of two multi-channel acousto-optical modulators 34. The laser gun is a multi-part receptacle for the adaptation of the optical unit and contains mounts 29 (Fig. 4a) with fitting surfaces for the fits of the terminators 26, means for combining the individual laser beams, the modulation unit, a transmission unit for the transmission of the laser radiation that is intended to produce a processing effect onto the processing surface, and an arrangement for neutralizing the laser radiation that is not intended to produce a processing effect. An arrangement for removing the material eroded from the processing surface can be arranged at the laser gun; this, however, can also be arranged in the proximity of the processing surface in some other way.

Fig. 4a shows a perspective illustration relating to Fig. 4.

Fig. 4b shows a modification of Fig. 4 wherein the ray beams of the individual fiber lasers do not proceed parallel as in Fig. 4 but at an angle relative to one another; this, however, cannot be seen from the sectional view in Fig. 4b and is therefore explained in greater detail in Figs. 21, 22 and 24.

Fig. 4c shows a modification of Fig.4b that enables an advantageous, significantly more compact structure as a result of a differently implemented transmission unit.

Fig. 4 shall be explained in detail first with the assistance of Fig. 4a. These explanations apply analogously to Figs. 4b and 4c.

In a housing 35, [respectively]4 fiber lasers F_{HD1} through F_{HD4}, F_{VD1} through F_{VD4}, F_{HR1} through F_{HR4}, F_{VR1} through F_{VR4}[,] via[the] terminators 26 with [the]mounts 29 (Fig. 4a)[,] are arranged in respectively four tracks of one beam packet H, being arranged side-by-side in a plane. The embodiment of the terminators 26 employed in Fig. 4 is described in greater detail in Fig. 9. The terminators should preferably be inserted gas-tight into the housing 35, to which end seals 36 (Fig. 4a) can be employed. Instead of the terminators shown in Figs. 4 and 4a, differently shaped terminators can also be employed, as described in

Figs. 5, 5a, 5b, 5c, 6, 6a, 7, 9, 9a, 10, 10a, 10b, 11, 11a and 12, when corresponding mounts 29 are provided in the housing 35. However, as also described under Fig. 3, single-mode fibers or other fibers 28 can be attached to the fiber lasers before the terminators 26 are attached. However, an arrangement of the laser fibers 5 or fibers 28 according to Figs. 40, 40a, 40b, 40c, 40d and 41 can also be employed. For example, the fiber lasers F_{HD1} through F_{HD4} or, respectively, F_{VR1} through F_{VR4} should have a different wavelength than the fiber lasers F_{VD1} through F_{VD4} or, respectively, F_{HR1} through F_{HR4}. For example, F_{HD1} through F_{HD4} and F_{VR1} through F_{VR4} should have a wavelength of 1100 nm whereas F_{VD1} through F_{VD4} or, respectively, F_{HR1} through F_{HR4} should have a wavelength of 1060 nm, which can be achieved by a corresponding doping of the laser-active core material of the laser fibers 5. However, all fiber lasers can also exhibit different wavelengths when they are correspondingly compiled[[sic]].

As explained in greater detail in Figs. 28 and 28a, the beam packets of the fiber lasers F_{HD1} through F_{HD4} are united with those of the fiber lasers F_{VD1} through F_{VD4} and the beam packets of the fiber lasers F_{VR1} through F_{VR4} are united with those of the fiber lasers F_{HR1} through F_{HR4} to form a respective beam packet F_{D1} through F_{D4} as well as F_{R1} through F_{R4} (Fig. 4a) via wavelength-dependent mirrors 37 as means for the combining. There are also other possibilities of influencing the wavelength of the fiber lasers; for example, wavelength-selecting elements such as Brewster plates, diffraction gratings or narrowband filters can be introduced in the region of the laser fibers between infeed mirror 7 and outfeed mirror 12. It is also possible to provide at least one of the two laser mirrors 7 or 12 with a mirror layer of a type that is adequately highly reflective only for the desired wavelength. The inventive execution of the beam merging, however, is not limited to the employment of fiber lasers with different wavelengths. In addition to fiber lasers that have no privileged direction in the polarization of the laser emission that is output, fiber lasers can also be employed that output a polarized laser emission. When the wavelength-dependent mirror is replaced by a mirror that is polarization-dependent such that it allows one polarization direction

to pass whereas it reflects the other polarization direction, only two differently polarized laser types need be employed in order to unite the two with the polarization-dependent mirror. In this case, the employment of the terminator 26 according to Fig. 9 having a quadratic cross-section is especially suitable, since the one or the other polarization direction can be respectively produced with the same fiber laser by turning the terminator by 90° before being mounted into the housing 35.

A particular advantage of the combining of a plurality of lasers to form a single spot, namely to each of the individual processing points B_1 through B_n (for example B_1 through B_4 in Figs. 20 through 22) is that a higher power density is achieved given a predetermined spot size on the processing surface 81.

The laser emission of the individual fiber laser can also be distributed onto a plurality of terminators, this being described in Fig. 15. This is particularly useful when materials are to be processed that manage with a low laser power or when the power of an individual fiber laser is adequately high. In such a case, it is conceivable that a laser gun 23 is equipped with only four terminators, for example F_{HD1} through F_{HD4}, for this purpose, F_{HD1} and F_{HD2} thereof, for example, being supplied by one fiber laser and F_{HD3} and F_{HD4} being supplied by a further fiber laser according to Fig. 15. When the principle described in Fig. 15 is applied twice, all four tracks F_{HD1} through F_{HD4} can be supplied by one fiber laser, this leading to an extremely cost-beneficial arrangement, particularly since further component parts such as wavelength-dependent mirrors and strip mirrors can be eliminated and, thus, an especially economical embodiment of the laser radiation source can be created.

By omitting fiber lasers or, respectively, tracks, further, the acquisition costs for such an arrangement can be lowered as needed and fiber lasers can be retrofitted later as needed. For example, one can begin with one fiber laser and one track. The lacking terminators of the fiber lasers that are not introduced are replaced for this purpose by structurally identical terminators that, however, do

not contain a through opening and no laser fibers and only serve for termination in order to close the housing 35 as though it were equipped with all terminators.

However, the laser radiation of a plurality of fiber lasers can also be combined and conducted into a single terminator, this being described in Fig. 16. For example, one can work with a plurality of fiber lasers combined in this way and with one track when, as described, the missing terminators are replaced by structurally identical terminators that, however, do not contain a through opening and no laser fibers in order to close the housing 35 as though it were equipped with all terminators.

Immediately after the ray beam has left the respective terminator, a part of the laser emission can be coupled out via a beam splitter (which, however, is not shown) and can be conducted onto a measuring cell that is not shown in the Figs. in order to produce a measured quantity therefrom that can be used as comparison value for a control of the output power of each and every fiber laser. However, laser emission can also already be coupled out of the laser fiber for the acquisition of a measured quantity before the terminator, this also not being shown.

The plurality of planes wherein the terminators are arranged is not limited to the one plane as described. For example, arrangements having three planes are recited in Figs. 29, 32, 33 and 41. An arrangement having two planes is shown in Fig. 38.

The respective beam packets of the fiber lasers are modulated via a respective four-channel acousto-optical modulator 34 whose functioning and embodiment is explained in greater detail in Figs. 17, 18, 19 and 19a. Using the acousto-optical modulator 34, which is a deflector in terms of principle, the unwanted energy in the case illustrated here is deflected out of the original beam direction I_0 into the beam direction I_1 (Fig.4a), so that it can be simply intercepted later in the beam path and neutralized. The modulation can preferably [ensue]occur digitally, i.e. a distinction is made between only two conditions in the individual modulator channels, namely "on" and "off", this being especially simple to control; however, it can also [ensue]occur in analog [in that]fashion

since the laser power in each modulator channel can be set to arbitrary values. The modulation is not limited thereto that the energy from the beam direction I_0 is employed for the processing and the energy from the direction I_1 is neutralized. Figs. 36, 36a, 36b, 36c and 37 recite examples wherein the beam direction 1_1 that is diffracted off is employed for processing and the energy from the direction I_0 is neutralized. Further, a slight part of the modulated radiant power of the individual modulator channels can be forward onto a respective measuring cell via a beam splitter (not shown) in order to generate a measured quantity that is used as a comparison value in a control circuit for the exact regulation of the laser energy of each track on the processing surface.

The multi-channel acousto-optical modulator 34 is preferably secured on a cylindrical modulator housing 41 that is rotatably seated in an opening 48 in the housing 35. After the modulator housing has been adjusted to the required Bragg angle α_B, the modulator housing is fixed with a connection 42. A seal 43 sees to it that each modulator housing terminates gas-tight relative to the housing 35. A specifically prepared printed circuit board 171 projects from the modulator housing 41 into the interior space 44 of the housing 35, electrical connections to the piezo-electric transducers 45 being produced thereover. The preferred embodiment of the modulators is described in greater detail in Figs. 19 and 19a.

After passing through the acousto-optical modulators, the beam packets F_{D1} through F_{D4} and F_{R1} through F_{R4} are conducted to a strip mirror 46 that is described in greater detail in Figs. 26, 26a, 27, 27a and 27b. The beam packets F_{D1} through F_{D4} is arranged [such]with respect to the strip mirror 46 such that it can pass through the strip mirror unimpeded. The laser beam bundles of the beam packet F_{R1} through F_{R4}, however, are offset by half a track spacing compared to the beam packet F_{D1} through F_{D4} and impinge the strips of the strip mirror arranged in strip-shaped fashion. As a result thereof, they are redirected in terms of their direction and now lie in one plane with the laser beam bundles F_{D1} through F_{D4}. An eight-track arrangement thus derives, whereby two lasers of different wavelengths are also superimposed in each track, so that a total of

sixteen lasers have been merged and take effect. Two beams I_1 that have been diffracted off in the acousto-optical modulator 34 are located above this plane I_0. Given a different adjustment of the acousto-optical modulator 34, the rays that are diffracted off can also lie under the plane of I_0, as shown in Figs. 4b and 4c.

A significant advantage of the inventive arrangement is that the symmetry axis [[sic]]of the beam packets F_{HD1} through F_{HD4} and F_{D1} through F_{D4} lie on the axis of the housing 35 that is defined by the bore 47, and the beam axes of the [appertaining]corresponding beam packets respectively lie parallel or at a right angle to this axis, which allows a simple and precise manufacture. However, it is also possible to arrange the beam packets asymmetrically and at different angles. Further, it is possible to correct small differences in the position of the beam packets by adjusting the wavelength-dependent mirrors 37 and of the[[sic]] strip mirror 46. It is possible to still re-adjust the terminators in position after they are mounted and in terms of their angular allocation, for example for individual optimization of the Bragg angles in the individual channels; this, however, is not shown in the Figures.

It lies within the scope of the invention that the plurality of tracks is reduced but can also be increased further; for example, by joining respectively eight instead of four terminators that are connected to fiber lasers to form a beam packet, a doubling of the number of tracks can be undertaken. [To]For this [end]purpose, two eight-channel acousto-optical modulators would have to be utilized. Acousto-optical modulators [have a]having 128 separate channels on a crystal can be commercially obtained.

Within the framework of the invention, it is likewise possible to arrange the fiber lasers in different planes for increasing the power per track and to superimpose their power on the processing surface, this being explained in greater detail in Figs. 29, 31, 32, 33 and 41 and/or to arrange a plurality of fiber lasers in bundles in order to superimpose their energy on the processing surface, this being described in Figs. 30 and 31.

Another possibility for increasing the number of tracks is described in Fig. 37.

Directly modulatable fiber lasers can also be utilized, this being described in greater detail in Fig. 23. In this case, the acousto-optical modulators are omitted and an especially simple structure derives.

Operation with a plurality of tracks of lasers and a plurality of lasers in a track enables high processing speeds given low relative speed between the laser gun and the workpiece. The processing speed can also thus be optimally adapted to the time constant of the heat elimination of the material. Given a longer operating time, [namely,]too much energy uselessly flows off into the environment.

The housing 35 is closed gas-tight with a cover and a seal, neither being shown in the Figures. A cylindrical tube 51 is flanged to the housing 35 in the region of the bore 47 and is sealed via a seal 52. The cylindrical tube contains as an optical[as] transmission unit[, namely] two tubes 53 and 54 each having a respective optical imaging system that image eight laser beam bundles F_{D1} through F_{D4} and F_{R1} through F_{R4} at the beam exit 10 (Fig. 1) onto the processing surface in the correct scale. Two optical imaging systems are preferably arranged following one another, since an extremely great structural length or a very small distance between the objective lens and the processing surface would otherwise derive, both being disadvantageous since a long beam path must be folded with mirrors and too small a spacing between objective lens and processing surface could lead to a high risk of contamination for the objective lens.

The beam path is shown as a side view in Fig. 4. The fundamental beam path is shown in Fig. 20 as a plan view for the beam packet F_{HD1} through F_{HD4}. The wavelength-dependent mirrors, the modulators and the strip mirrors are not shown therein. The Figures mainly show plano-convex lenses; however, it is also possible to utilize other lens forms such as, for example, biconvex or concave-convex lenses or lenses having an aspherical shape in all figures. Lens systems

that are respectively composed of a plurality of lens combinations can also be employed.

In order to transmit the laser energy as efficiently as possible and keep the heating of the optical components within limits, all optical surfaces occurring in the various embodiments of the laser radiation source are anti-bloomed with outmost quality for the wavelength range coming into consideration. The optical imaging systems can preferably be telecentrically implemented.

There are also other advantageous solutions for the transmission unit in order to shorten the structural length of the transmission unit and thereby nonetheless achieve a large spacing between the objective lens and the processing surface, as is shown in even greater detail in, among others, Figures 4b and 4c. The lenses 55 and 56 can be connected to the tube 53 by screwed connections or by gluing; however, they can also be preferably metallized at their edges and soldered to the tube 53. The same is true of the lenses 57 and 61 in the tube 54. A gas-tight seal of the lenses and a good heat transmission from the lenses to the tubes thus derives. The tube 54 is preferably terminated gas-tight relative to the cylindrical tube 51 with a seal 62. With respect to tightness and cleanliness, the same conditions apply to the space 63 as apply to the space 44 and, likewise, to the spaces 64 and 65 within the tubes 53 and 54. The chambers 66 and 67 are preferably connected to the spaces 44 and 63 via bores 71. The tubes 53 and 54 can preferably comprise openings 72.

An intercept arrangement 73 for neutralizing the laser radiation that is not intended to produce any processing effect on the processing surface and that comprises a high-reflectivity mirror 74 and a dispersion lens (concave lens) 75 projects into the space 63. The principle of the intercept arrangement 73 is described in greater detail in Fig. 18. The intercept arrangement 73 is introduced with a seal 76, and the concave lens 75, which can also be replaced by some other optical element, for example a glass plate, is glued into the intercept arrangement or is preferably metallized at an image edge zone and soldered to the intercept arrangement for better heat elimination. The space 63 is thus closed off gas-tight

from the environment. What derives as a result of the described [measures]techniques is that the entire interior of the laser gun is sealed gas-tight from the environment. The spaces 44, 63, 64 and 65 and the chambers 66 and 67, i.e. the entire interior of the laser gun, can be preferably evacuated or filled with a protective atmosphere. The spaces and chambers should be as free as possible of components that output gases or particles because dirt could otherwise settle on the highly stressed optical surfaces, which would lead to a premature failure of the arrangement. The [demand is therefore also made of the]seals to be employed [that they]should not give off any particles or gases. Ultimate cleanliness of the parts to be assembled and of the environment has great value [attached to]associated with it during assembly until the laser gun has been closed. After the closing of the laser gun 23, an evacuation of the entire interior can be undertaken via the valve 77 or a protective atmosphere can be filled in. The advantage of filling the interior with protective atmosphere is that it is simpler to replenish in that a gas bottle (not shown) is connected to the valve 77 during operation via a pressure-producing valve, gas being capable of being refilled into the housing therefrom as needed. Another advantage is that, when a terminator is to be removed from the housing for the replacement of a fiber laser and is to be replaced by another or when the housing or, respectively, the cylindrical tube must be opened by the user for some reason or other, a slight quantity of the protective atmosphere can be allowed to flow through the housing during the procedure in order to thus prevent the penetration of dirt particles into the protected space. A slight quantity of the gas can also be allowed to constantly flow through the housing and escape such through openings, preferably in the proximity of the objective lens[, that t]. This flow also prevents a contamination of the objective lens by dirt particles that are released during the processing event (Fig. 39a). The evacuation or the filling with protective atmosphere can also be foregone when a shorter service life of the laser radiation source is accepted.

It is advantageous in the arrangement according to Fig. 4 that the angle between the beam packets of the original beam direction I_0 of the acousto-optical

modulator and the beam direction I_1 that is diffracted off is noticeably increased by the imaging system composed of the lenses 55 and 56, so that it is simple to intercept the unwanted radiation packet of the deflected beam direction with the highly reflective mirror 74 at the intercept arrangement 73. The mirror 74 is preferably fabricated of metal and is provided with a highly reflective layer in order to keep the heating as a consequence of absorbed laser energy low. For better heat elimination, it is connected via a strong flange of the intercept arrangement 73 to the tube 51. However, the intercept arrangement can also be foregone when the highly reflective mirror is replaced with an optical component such as, for example, a lens that slightly modifies the optical properties of the laser radiation to be intercepted such that the focus of the radiation that is diffracted off is different from the focus of the radiation employed for processing the material. If the radiation to be intercepted would then also be conducted onto the processing surface, the radiation to be intercepted would not have the required power density in order to erode material but would be uselessly absorbed and reflected. The advantage of the arrangement according to Fig. 4 is [comprised therein] that low demands are made of the optical components in the two tubes. The two tubes could also be implemented completely the same. Another advantage is [comprised therein] that the axes of the terminators 26 lie parallel to one another. The distance between the objective lens 61 and the processing surface 81 dare not be too small, so that particles that fly off from the material surface do not proceed onto the objective lens. When it is contaminated, [namely,]it then[it] absorbs the laser energy that passes[three and], is destroyed, and is thus unuseable. In order to prevent the contamination, a special mouthpiece 82 is arranged between the objective lens 61 and the processing surface 81, this being described in greater detail under Fig. 34.

The laser gun 23 of the laser radiation source is rotatable around the optical axis that is identical to the axis of the cylindrical tube 51, 95 within the arrangement for processing materials (Fig. 3), for example on a prism 83, and is seated displaceable in the direction of the optical axis and fixed in its position

with a strap retainer 85 or with a plurality of strap retainers. As a result thereof, an exact delivery of the laser gun to the processing surface 81 is possible. A plate 86 that comprises openings 87 through which a coolant can be pumped is located outside the prism 83. The job of this plate 86 is to intercept and divert the laser energy intercepted from the beam path of the transmission unit, this being shown in greater detail in Fig. 18. A heat dam that, however, is not shown in the Figs., is located between the plate 86 and the tube 51, 95, 113. The plate is connected to the tube 51, 95, 113 via insulating flanges 91. The flanges 91 also prevent the emergence of laser radiation.

By turning the laser gun 23 around its optical axis, the track spacing of the laser tracks on the processing surface 81 can be modified, this being shown in greater detail in Fig. 35. It lies within the scope of the invention that the turning of the laser gun for setting the track spacing as well as the setting of its spacing from the processing surface can be implemented not only exclusively manually but with the assistance of a suitable, preferably electronic control and/or regulation. Suitable measuring devices (not shown) can also be inventively provided for this purpose, these being located in the proximity of the processing surface and being capable of being approached by the laser gun as needed. A further possibility for adjusting the track spacing is described in Figs. 36, 36a, 36b, 36c and 37. A manually or motor-adjustable vario-focusing optics can also be utilized for setting the track spacing. Such a vario-focusing optics, in addition to permanently arranged lenses, preferably has two movable lens system, whereby an adjustment of the first lens system mainly effects an adjustment of the imaging scale, with which the track spacing can be influenced, and whereby an adjustment of the second lens system mainly effects an adjustment of the focusing. An iterative setting can be undertaken for optimizing track spacing and best focus. It is also possible to arrange a displaceable lens (not shown) having a long focal length, preferably between the lenses 57 and 61, with which the focusing of the processing points on the processing surface can be finely readjusted without

having to displace the radiation source because the resultant focal length of two lenses is dependent on their spacing.

As a result of the high laser power, the optical elements in the beam path will heat, since they absorb a part, even though a slight part, of the laser energy. Preferably, the critical optical components are therefore not made of glass but of a material having better thermal conductivity, for example of sapphire. The waste heat, given metallization of the connecting surfaces of the optical components, is eliminated by the solder connections to the mounts and to the housing. For better heat output, the housing is implemented with cooling ribs 92 that can be cooled by a ventilator (not shown). A permeation of the housing 35 as well as of the other component parts of the laser radiation source with bores is also possible, particularly in the critical regions at the lens mounts and mounts for the terminators 26, a coolant being capable of being pumped therethrough, as shown in Figs. 8 and 39.

Since, as presented above, extremely high laser powers are required in processing of materials, it is critical to the invention to keep the plurality of optical elements, particularly lenses, in the beam path as low as possible in order to keep the optical losses and the risk of contamination of the optics, which would always lead to a premature failure, as low as possible. It is also lies within the scope of the invention that the objective lens (61, 103 and 112) is equipped with an interchangeable mount so that it can be quickly replaced by the user of the laser radiation source as needed, whether because it has been contaminated during operation or because a different imaging scale is requested. In this case, it is advantageous that the bore 72 and the tube 54 is not implemented.

It also lies within the scope of the invention that [measures]<u>techniques</u> are undertaken in the optical beam path so that no laser energy can proceed back into the lasers. It is shown in Fig. 3 that the laser radiation impinges the material to be processed not perpendicularly but at an angle, so that the radiation reflected at the material surface cannot proceed back into the laser radiation source. It is also shown in Figs. 4, 4b, 4c and Fig. 18 that the laser radiation to be destroyed can be

conducted by an obliquely placed concave lens 75 into a sump composed of an obliquely placed plate 86 that can be cooled. Instead of the concave lens of 75, some other optical component, for example a plate or a diaphragm, can also be inventively employed. The effective diameter of this optical component is thereby dimensioned such that the laser radiation conducted into the sump can just pass, whereas radiation that is reflected back from the sump or is dispersed back, is largely retained, so that no energy can proceed back into the laser. Inventively, the surface of the plate 86, which is shown as a planar surface in the Figures, can also be implemented crowned or hollow and can be preferably roughened in order to absorb a maximum of radiation and reflect or, respectively, disperse a minimum of radiation.

It is also shown for two planes in Fig. 8 that, as a result of a slight parallel offset of the beam axes of the ray beams emerging from the terminator, an oblique incidence onto all effected lens surfaces can be achieved. This also applies for the arrangement having one or more planes. The acousto-optical modulator 34 is already rotated by the angle α_B relative to the axis of the ray beam; however, it can also be additionally rotated by the angle γ relative to the symmetry axis of the ray beam or an arrangement according to Fig. 24 can be employed wherein the axes of the ray beams emerging from the terminators proceed at an angle relative to one another. It has been shown in practice that angular differences of 1 through 2 degrees between the perpendicular onto the optical surface and the axis of the beam bundle are already adequate in order to achieve protection against radiation reflected back into the laser.

It lies within the scope of the invention to select embodiments of the optical, mechanical and electrical arrangement for Fig. 4 deviating from the described embodiment. For example, the radiation packets F_{D1} through F_{D4} and F_{R1} through F_{R4} could be focused onto the processing surface by a shared lens, similar to that shown in Fig. 31, which in fact yields a very high powered density but cannot present the shape of the processing spot as well since all processing points lie on one another and are united to form a common spot.

Fig. 4b shows another inventive laser gun for a laser radiation source that differs from the laser gun shown in Fig. 4 on the basis of a housing 93, terminators 94, a cylindrical tube 95, a tube 96 and on the basis of a highly reflective mirror 97.

The housing 93 has mounts 29 fitting the terminators 94. The terminators 94 preferably correspond to those of Figs. 10, 10a and 10b; the axes [[...]]of the ray beams do not proceed parallel in the [appertaining]corresponding beam packets. Rather, they proceed somewhat toward the center of the concave lens 101, which is shown in the plan view 21. However, all other terminators according to Figs. 5, 5a, 5b, 5c; 6, 6a; 7, 9, 9a; 11, 11a and 12 can also be employed when it is [seen to]insured that the mounts 29 therefor are arranged at a corresponding angle. The transmission unit is located in the tube 96, this transmission unit being composed of three lenses, namely a dispersion lens, i.e. a concave lens 101, and two positive lenses, i.e. convex lenses 102 and 103, whereby the convex lens 103 is preferably implemented as an interchangeable objective lens. For the mounting of the lenses with respect to tightness and heat elimination, [that]what was stated [under]as to Fig. 4 and Fig. 4a applies, as it does for the selection of material with respect to the heat conduction.

The tube body 96 can be evacuated in the space between the lenses 101 and 102 or can be filled with a protective atmosphere or, preferably, be connected to the space 105 via a bore 104, said space 105 being in turn connected via a bore 106 to the space 107. The space 107 is connected to the space 111 via the bore 47, said space 111 being in turn terminated gas-tight, as described under Fig. 4 and Fig. 4a. The space between the lenses 102 and 103 can be connected via a bore (not shown) to the space 105, particularly when the mount of the objective is closed gas-tight or, as described under Fig. 4, when a slight amount of the protective atmosphere constantly flows through the laser gun and emerges in the proximity of the objective lens, this, however, not being shown in Fig. 4b. The entire interior of the laser gun, composed of the spaces 111, 105, 107, is preferably evacuated or filled with a protective atmosphere or, respectively,

flooded by a protective atmosphere, as was described in detail under Fig. 4 and Fig. 4a. The undesired ray beams are intercepted with a highly reflective mirror 96; in contrast to Fig. 4, however, no lens system is present that has an angle-enlarging effect, so that the distance between the highly reflective mirror and the modulators is kept correspondingly large here in order to achieve an adequate spatial separation of the beam packets I_0 and I_1. Nonetheless, the entire structural length of the laser gun is similar here to the arrangement of Fig. 4. The optical beam path of the transmission unit in Fig. 4 represents a side view. Fig. 21 indicates a fundamental beam path for a plan view relating to Fig. 4b. The beam path of the lenses 101 and 102 corresponds to that of an inverted Galileo telescope; however, it can also be implemented as an inverted Kepler telescope when the concave lens 101 having a short focal length is replaced by a convex lens. Such telescopes are described in the textbook "Optik" by Klein and Furtak, Springer 1988, pages 140 through 141. The advantage of the arrangement according to Fig. 4b is that only three lenses are required for the transmission unit. The disadvantage, to wit that the ray beams of the individual terminators do not proceed parallel, is eliminated by terminators according to Figs. 10, 10a and 10b.

A lens 55 could also be employed in order to deflect the ray bundles into the desired direction, as was shown in Fig. 20. The individual laser ray bundles would then proceed parallel to one another between the terminators 26 and the lens 55, that is arranged as in Fig. 4, and no difference from Fig. 4 derives with respect to the housing and the terminators or, respectively, their arrangement. Since, however, the lens 55 also exercises a collecting effect on the individual ray bundles in addition to the deflecting effect, the same conditions as in Fig. 21 would not arise at the location of the concave lens 101. This, however, can be compensated by a different adjustment of the spacing of the fiber 28 or, respectively, of the laser fiber 5 from the lens 133 or by a modification of the lens 133 in the terminators 26, i.e. the ray cone of the laser ray bundle from the individual terminators would be respectively set such that a sharp image

respectively derives on the processing surface at the location of the points B_1 through B_n.

According to the invention, it is also possible to combine the lenses 102 and 103 to form a single, shared lens. A transmission unit having only two lenses then derives. It is also possible to arrange a displaceable lens (not shown) with a long focal length between the lenses 101 and 102, the focusing of the processing points on the processing surface being capable of being finely readjusted therewith without displacing the radiation source. A vario-focusing optics can also be employed, as was mentioned under Fig. 4.

A special mouthpiece 82 is provided at the laser gun 23 that is intended to prevent a contamination of the objective lens 112 and that is described in greater detail under Fig. 34.

Fig. 4c shows a laser gun that is even more significantly compactly implemented than that of Fig. 4 and Fig. 4a. In combination with a mirror arrangement, an objective lens 112 is employed as transmission unit and this can be interchanged for achieving different imaging scales. As already described under Fig. 4, a vario-focusing optics can also be employed. Inventively, however, an imaging can [ensue]<u>occur</u> with the mirror arrangement by itself without additional objective lens 112.

Fig. 4c differs form Fig. 4b in terms of the following points:[ ] The cylindrical tube 95 is replaced by an eccentric tube 113. The tube body 96 is preferably replaced by a plate 114 having a concave mirror 115 and a mount 116 with an objective lens 112 and a highly anti-bloomed plate 117. The intercept unit 73 is given an arced (convex) mirror 121 above the highly reflective mirror 97. The eccentric tube is connected to the housing 93 at one side. A seal 52 sees to the required tightness. The plate 114 is introduced into the eccentric tube 113, said plate 114 containing a passage for the beam packets I_0 and I_1 and carrying the concave mirror 115 whose dissipated heat can thus be diverted well to the eccentric tube. The eccentric tube has two axes that are preferably parallel to one another, namely, first the symmetry axis of the entering beam packets having the

direction I_0 that are directed onto the arced mirror and, second, the axis between concave mirror and objective lens 112 that can be considered as an optical symmetry axis for the emerging laser radiation.

Inventively, the beam path is folded with the two mirrors 121 and 115. The arced mirror 121 is preferably fabricated of metal. It is intimately connected to the highly reflective mirror 97 and is preferably fabricated of one piece therewith. The convex surface of the arced mirror can be spherically or aspherically shaped. The mirror 115 is concavely shaped, i.e. a concave mirror. Its surface can be spherically shaped but is preferably aspherically shaped. It is preferably composed of metal. Metal has the advantage of good elimination of the waste heat. A considerable advantage given manufacture of metal also derives in the production of aspherical surfaces, which, in this case, can be produced by known diamond polishing lathing methods, as can also spherical and planar surfaces. As a result thereof, the highly reflected mirror 97 and the arc mirror 121 can be manufactured of one piece and, preferably, in one work pass having the same shape of the surface and can be mirrored in common, which is particularly simple in terms of manufacture and very advantageous for the positional stability of the arced mirror. In the modulation of the laser energy with the acousto-optical modulator, it impinges either the arc mirror 121 or the highly reflective mirror 97. The waste heat that is produced remains the same in any case and the arced mirror stays at its temperature and, thus, its position, which is very important since it is preferably implemented with a short focal length and the imaging quality of the arrangement is therefore very dependent on its exact position. In this case, the arced mirror 121 has advantageously co-assumed the function of the highly reflected mirror 97. The highly reflective mirror 97 can[97 [sic]], however, also have some other form of[the] surface than the arced mirror 121 and, for example, can be a plane mirror.

The beam path is similar to that of an inverted mirror telescope of Herschel that, however, contains a convex lens instead of the arced mirror and that is described in greater detail in Fig. 22. Mirror telescopes are described on

page 152 in the "Lehrbuch der Experimentalphysik Band III, Optik" by Bergmann-Schäfer, 7th edition De Gruyter 1978. The arced mirror can also be replaced by a concave mirror having a short focal length. As a result thereof, the structural length would be slightly enlarged and different ray cones of the ray bundles emerging from the terminator would have to be set in order to obtain a sharp image in the image plane. The arced mirror could also be replaced by a convex lens having a short focal length. Another folded mirror would then have to be utilized in order to preserve the compact structure. The intercept arrangements 73 is attached gas-tight to the eccentric tube via a seal 76 the undesired laser energy, as described under Figs. 4, 4b and 18, being diverted via said intercept arrangement 73 to a cooling plate 86 with bores 87 and being neutralized. It is also possible to already intercept the undesired laser radiation from the beam packet I_1 at the location of plate 114 and neutralize it.

The space 111 in the housing 93 is connected to the cavity 123 via the bore 122. Both spaces can be evacuated[or],[preferably, be] filled with a protective atmosphere, or[, respectively,] flooded by a protective atmosphere, as already described. The mount 116 that accepts the interchangeable objective lens 112 is attached to the end of the eccentric tube 113 that resides opposite the housing 93. A seal 124 closes the cavity 123 gas-tight. The mount can also accept an anti-bloomed plate 117 whose edge is preferably metallized and that is preferably soldered gas-tight to the mount. Its job is to keep the cavity 123 gas-tight when the objective lens was removed for cleaning or when an objective lens having a different focal length is to be introduced in order to generate a different imaging scale. The space between the objective lens 112 and the highly anti-bloomed plate 117 can also be connected to the space 123 via bore (not shown), particularly when the entire laser gun, as described under Fig. 4, constantly has a protective atmosphere flowing through it, this emerging in the proximity of the objective lens 112, which is shown in Fig. 39a. The highly anti-bloomed plate 117, however, can also contain optical correction functions, as known for the Schmidt optics known from the literature, in order to thus improve the optical

imaging quality of the arrangement. However, it is also possible to omit the highly anti-bloomed plate, particularly when it contains no optical correction function and the objective lens was introduced gas-tight or a protective atmosphere flowing therethrough sees to it that no dirt can enter into the space 123 when the objective lens is replaced. A special mouthpiece 82 is provided at the laser gun 23, this being intended to prevent a contamination of the objective lens 112 and being described in greater detail under Fig. 34.

The eccentric tube can be provided with cooling ribs 92 over which a ventilator (not shown) can blow in order to eliminate the waste heat to the environment better. The laser gun is rotatably seated in a prism around the axis between concave mirror and objective lens in order, as described under Fig. 4, to make the track spacing adjustable and in order to set the correct distance from the processing surface 81. The laser gun can be fixed with a strap retainer 85.

It is possible to arrange a displaceable lens (not shown) having a long focal length between, preferably, the concave mirror 115 and the objective lens 112, the focusing of the processing points onto the processing surface being capable of being finely readjusted therewith without displacing the laser gun. However, a variable focusing optics can also be utilized, as was described under Fig. 4. All descriptions that were provided for Figs. 4, 4a and 4b also apply analogously.

Fig. 5 shows a preferred embodiment of a terminator 26 for a fiber 28 or laser fiber 5, which is also a fiber. Plug-type connections for optical fibers for low powers are known in optical communications technology, in sensor applications and [mensuration]measurement technology; these, however, are not suitable for high powers because too much heating occurs, this leading to destruction. For example, such laser diode collimator systems, beam shaping optics and coupling optics are described in the catalog 1/97 of Schäfter & Kirchhoff, Celsiusweg 15, 22761 Hamburg, pages A1 through A6. However, the power of these systems is limited to 1000 mW and is thus below the demands for the desired applications in processing materials by [the]a factor of 100 because an

adequate heat elimination is not assured. Further, these systems are relatively large in diameter, so that no high packing density of the laser outputs can be achieved. Another great disadvantage is[comprised therein] that these systems are not adequately sealed; they would get dirty very quickly and burn up due to an increased absorption of the laser radiation. Last but not least, it should also be mentioned that the precision of the mount for fibers and the lens are [[sic]] inadequate for the desired application. Terminators according to this patent application are therefore significantly more advantageous. Such terminators can be advantageously employed for coupling laser radiation out of a fiber 5, 28, as disclosed in the German Patent Application P 198 40 935.4 of the assignee "Abschlussstück für Lichtleitfasern".

This terminator 26 can be fundamentally used for all applications wherein the matter of concern is that the ray bundle emerging from a fiber 5, 28 be precisely coupled with a releasable connection. It is likewise possible with the assistance of this terminator to produce a precise, releasable connection of the fiber 5, 28 to the remaining optics. The terminator is composed of an oblong housing 132 that comprises a through cylindrical opening 130 extending in axial direction. The housing is preferably manufactured of prefabricated, for example drawn material that can preferably be composed of glass. The laser fiber 5 of the fiber laser is preferably stripped of its cladding at its ultimate end and is preferably roughened at its outside surface, this being disclosed in German Patent Application P 197 23 267, so that the remaining pump radiation leaves the laser fiber before the entry of the laser fiber into the terminator. The fiber 5, 28 can also be additionally surrounded by a single-layer or multi-layer protective sheath 131 that can be connected to the housing 132 of the terminator, for example with a glued connection 142. The housing 132 comprises fits 134 with which the housing can be exactly introduced in a mount 29 (Fig. 5a, Fig. 7, Fig. 8, Fig. 14). The fits can thereby extend over the entire length of the housing (Figs. 5b, 9, 10); however, it can also be attached in limited regions of the housing (Figs. 5, 6, 7). One or more seals 36 can be provided that, for example, are connected to the

housing 132 with glue connections 142. The job of the seals is to enable a gas-tight connection of the terminators to the mounts 29. The housing can have a different diameter, for example a smaller diameter, in the region of the protective cladding 131 and of the seal 36 than in the region of the fits. At the end of the housing 132, the end of the fiber 28 or, respectively, of the laser fiber 5 is accepted and conducted within the housing in the opening 130. A lens 133 having a short focal length is secured to the other end of the housing 132, whereby the housing can comprises a conical expansion 139 so as not to impeded the laser radiation 13. Means can be provided for adjusting the position of the fiber 5, 28 within the terminator in order to adjust the position of the fiber relative to the lens 133 within the terminator and with reference to the fits 134, as shown in Figs. 5b, 5c, 6, 6a, 7, 9, 9a, 10a, 10b, 11, 11a and 12. The radial position of the fiber 5, 28 can also be defined by the cylindrical opening 130, whereby the fiber is axially displaceable within the opening. The position of the lens 133 can either be adequately precisely mounted during assembly or can be axially and/or radially adjusted and fixed with suitable means (not shown) with reference to the fiber 5, 28 and to the fits 134, whereby the fiber can also be axially displaced (Fig. 5b). The adjustments are advantageously undertaken with a measuring and adjustment device. What the adjustment is intended to achieve is that the ray bundle 144 emerging from the lens 133 is brought into a predetermined axial and focus position with a defined cone relative to the fits 134. After a fixing of the fiber 5, 28 within the housing 132 and of the lens 133 at the housing, the measuring and adjustment device is removed. Inventively, it is also possible to provide the end of the fiber 5, 28 with a suitable coating, for example a correspondingly thickly applied metallization 141, in the region of the terminator before assembly in order to further improve the durability of the adjustment. The fixing of the fiber 5, 28 within the housing 132 can [ensue]<u>occur</u> with suitable means such as gluing, soldering or welding. An elastic compound 138 that represents an additional protection for the fiber is preferably provided at the transition between the housing 132 and the protective sheath 131. It is also inventively possible to

fashion and align the lens 133 by corresponding shaping and vapor-deposition of a corresponding layer, preferably at its side facing toward the fiber end, such that it co-assumes the function of the outfeed mirror 12 for the fiber laser.

Fig. 5a shows a multiple arrangement of fiber laser outputs with the terminators from Fig. 5. Bores 150 for the acceptance of two terminators 26 for two tracks are provided in a housing 145. Further, respectively three pins 148 and 149 are attached in rows such within the housing 145 in extension of the bores that they represent a lateral limitation as mount 29 for the terminators and see to a precise guidance and alignment of the terminators. The diameters of the pins 148 are referenced d_1 and are preferably identical to one another. The diameters of the pins 149 are referenced d_2 and are preferably likewise identical to one another. If the diameters of the pins 148 were the same as the diameters of the pins 149, the axes of the ray beams of both tracks would lie parallel to one another in the plane of the drawing since the terminators 26 comprise cylindrical fits 134. In Fig. 5a, however, the diameters of the pins 149 are shown larger than the diameters of the pins 148, this [leading thereto that]<u>resulting in</u> the axes of the two ray beams [proceed]<u>proceeding</u> at an angle relative to one another in the plane of the drawing. The angle between the ray beams is dependent on the diameter difference $d_2 - d_1$ and on the center-to-center spacing m of the two pin rows. The terminators are conducted through the housing 145 at the underside in one plane and are conducted from above through a cover (not shown) of the housing that is secured to the housing and can close it gas-tight with a seal (not shown). The housing 145 can be part of a receptacle for an optical unit for shaping the laser radiation. The terminators are secured to the housing 145 with clips 147 and screws (not shown), whereby the seals 36 see to a gas-tight closure. The arrangement is not limited to two tracks; further bores 150 can be provided and further pins 148 and 149 can be introduced in order to insert further terminators for further tracks. The arrangement is not limited to the one plane as described; further bores 150 can be inserted into the housing 145 in further tracks and in one or more further planes, these lying above or below the plane of the drawing, and

the pins 148 and 149 are lengthened to such an extent that they represent mounts 29 for all tracks and all planes. Inventively, pins 148 and 149 are likewise employed for producing a defined spacing between the planes. In this case, the pins proceed horizontally between the terminators. For example, the horizontally arranged pins 149 proceed between the wall of the housing 145 wherein the bores 150 lie and the row of illustrated, vertically arranged pins 149. The horizontally arranged pins 148 preferably proceed at a spacing m parallel to the horizontally arranged pins 149. Horizontally arranged pins are not shown in Fig. 2a. The pins 148, 149 are preferably fabricated of drawn steel wire; however, they can also be composed of other materials, for example of drawn glass. An advantage given the arrangement with a plurality of tracks and/or planes in the illustrated way is that the [rods [sic]]<u>pins</u> 148, 149 exhibit a certain flexibility. As a result thereof, it is possible to press the entire packet of the terminators together in the direction of the tracks and in the direction of the planes such that the terminators 26 with their [fits]<u>fittings</u> 134 lie against the pins without spacing, this being desirable for achieving utmost precision.

Fig. 5b shows a terminator 26, whereby means for adjusting the position of the fiber 5, 28 within the terminator are provided in order to be able to adjust the position of the fiber 5, 28 relative to the lens 133 within the terminator and with respect to the [fits]<u>fittings</u> 134. The position of the lens can also be adjusted. The adjustments are advantageously undertaken with an adjustment device. Adjustment screws 135, 136 (Figs. 5b, 5c, 9, 9a, 10a, 10b, 11, 11a, 12) and/or [or [sic]]balls 137 (Figs. 6, 6a, 7) can be provided for the adjustment of the position of the fiber 5, 28 in the housing 132. The fiber 28 or[, respectively,] laser fiber 5 can also be axially displaced within the adjustment screws 135, 136 or balls 137. The position of the lens 133 can either be adequately precisely mounted during assembly or axially and/or radially adjusted and fixed by means (not shown) with reference to the fiber 5, 28 and with reference to the [fits]<u>fittings</u> 134, whereby the fiber can also be axially displaced. The adjustments are advantageously undertaken with a measuring and adjustment device. What the adjustment is

intended to achieve is that the ray bundle 144 emerging from the lens 133 is brought into a predetermined axial and focus position with a defined cone on the basis of a relative advance of lens 133 and fiber 5, 28 toward the fits 134. After a fixing of the fiber 5, 28 within the housing 132 and of the lens 133 to the housing, the measuring and adjustment device is removed. That stated under Fig. 5 for this and the other embodiments continues to apply, for example regarding the metallization 141, the elastic compound 138 and the employment of the lens 133 as laser mirror.

Fig. 5c shows a cross-section through the terminator 26 in the region of the adjustment screws, from which it can be seen that preferably three adjustment screws 135 are provided distributed over the circumference, the fiber 28 or, respectively, the laser fiber 5 being adjustable in fine fashion in the housing therewith. Further, further adjustment screws 136, as shown in Fig. 5b, can be provided within the terminator at the end of the terminator at which the fiber 28 or, respectively, the laser fiber 5 enters. These adjustment screws are [fashioned]designed like the adjustment screws 135. When only one set of adjustment screws 135 is employed, the fiber 28 or[, respectively,] the laser fiber 5 can only be adjusted with respect to the angle. When two sets of adjustment screws are employed, they can also be displaced parallel to their axis. The fixing of the fiber 5, 28 within the housing 132 can [ensue]occur with suitable means such as gluing, soldering or welding.

Fig. 6 shows an embodiment of the terminator 26 wherein small balls 137 of metal or, preferably, metallized glass are employed instead of adjustment screws, these being brought into their position in the housing and being subsequently glued or soldered. A plurality of sets of balls can also be applied.

Fig. 6a shows a cross-section through the terminator in the region of the balls 137.

In order to prevent the optical surfaces on the optical fiber and the side of the lens 133 that faces toward the optical fiber from contaminating biparticles in the ambient air, the connections in Figs. 5, 5b, 5c, 6, 6a, 7, 9, 10, 11, 11a and 12

between the lens 133 and the housing 132 as well as between the adjustment screws 135 and 136 or, respectively, the balls 37 and the housing 132 can be hermetically closed. This can [ensue]occur with suitable glued or soldered connections 142. When a soldered connection is preferred, the glass parts are previously metallized at the corresponding locations 141. In order to achieve a greater strength, the glued or soldered connections can also entirely or partially fill the remaining gap between the fiber 28[or, respectively], the laser fiber 5 and the housing 132, or[, respectively,] the protective sheath 131 in the proximity of the terminator, this being shown, by way of example, in Fig. 5. It is also possible to durably evacuate the interior 143 of the housing or fill it with a protective atmosphere.

Fig. 7 shows a further embodiment of a terminator 26 that is introduced in a housing 145 with a mount 29. Given this embodiment, the front, outer [fit]fitting 134 in the region of the lens 133 is conically implemented for better sealing and for better heat elimination. Additionally, a seal 146 can be provided that instead of being attached to the lens-side end of the terminator as shown, can also be attached to the fiber-side end thereof.

Fig. 8 shows mounts 29 in a housing 145 for a plurality of conically implemented terminators 26 according to Fig. 7. Such mounts are advantageous when a plurality of outputs of fibers or[, respectively,] fiber lasers are to be arranged next to one another or next to one another and above one another. The axes of the mounts can thereby be arranged such that the axes of the ray beams emerging from the terminators of the terminators lying side-by-side and/or above one another proceed parallel to one another or at an angle. In order to eliminate the waste heat, the housing 145 can be inventively provided with bores through which a coolant is conducted.

Fig. 8a shows the rear fastening of the terminators 26 in the housing 145. For fixing the terminators 26, 94, clips 147 are provided that fix the ends of the terminators with screws 151 in the housing at the locations at which the fibers respectively enter into the housing of the terminators 26, 94.

Fig. 9 shows an embodiment of a terminator 26 having a quadratic or rectangular cross-section, whereby all outside surfaces [lying]lie opposite one another proceed parallel and can be [fits]fittings 134. Fig. 9a shows a cross-section through the [end piece [sic]]terminator 26 according to Fig. 9 having a quadratic cross-section.

Fig. 10 shows an embodiment of the terminator 94 with rectangular cross-section, whereby two outside surfaces lying opposite one another proceed trapezoidally and two outside surfaces lying opposite one another proceed parallel to one another. The outside surfaces can be [fits]fittings 134.

Fig. 10a shows a longitudinal section and Fig. 10b a cross-section through the terminator according to Fig. 10.

Fig. 11 shows terminators 26 having trapezoidal cross-sections, so that a row of terminators arises by successive turning of the terminators by 180° when a plurality of terminators are joined to one another, whereby the center points of the terminators lie on a central line. When desired, a plurality of such rows can be arranged above one another, which is indicated with broken lines in Fig. 11.

Fig. 11a shows terminators 26 with a triangular cross-section that can likewise be arranged in a plurality of rows above one another, this being indicated with broken lines.

Fig. 12 shows terminators 26 having a hexagonal cross-section that can be arranged honeycomb-like for increasing the packing density.

The inventive terminators advantageously enable the laser radiation source to be built of individual modules.

Fig. 13 shows an applied example of the terminator 26 or[, respectively,] 94 given a fiber 28 or[, respectively,] a laser fiber 5 that have both ends provided with a respective, inventive terminator.

According to the invention, it is possible to preferably implement the lens 133 at its side facing toward the fiber end on the basis of a corresponding shape being and vapor-deposition of a corresponding layer such that it co-assumes the function of the outfeed mirror 12. According to the invention, it is also possible

to implement the lens 3, 154 by corresponding shaping and vapor-deposition of a corresponding layer that it co-assumes the function of the infeed mirror 7.

It is fundamentally possible to combine a plurality of the terminators described above in a plurality of tracks side-by-side and above one another in a plurality of planes to form a packet.

It is also possible to implement the shape of the terminators differently from that shown in the Figures, for example that a cylindrical shape according to Fig. 6 is lent trapezoidal or rectangular fits according to Fig. 9 or Fig. 10.

Fig. 14 shows a coupling of the laser fiber 5 to a pump source with the terminator 26 via the housing 152 in which the pump source 18 is accommodated in a recess 153, preferably gas-tight. A seal 146 assures that the terminal 26 likewise terminates gas-tight, so that no dirt particles can penetrate into the recess from the outside and, as needed, it can be evacuated or filled with a protective atmosphere. A constant current of a protective atmosphere can also flow through the recess 153, particularly given temporary removal of the terminator 26. The radiation of the pump source 18 is focused onto the pump cross-section of the laser fiber 5 via a lens 154. The pump source can be composed of one or more laser diodes; however, it can also be composed of an arrangement of one or more lasers, particularly fiber lasers as well, whose output radiation was united such with suitable means that a suitable pump spot arises.

Fig. 15 shows the branching of the output radiation from the laser fiber 5 of a fiber laser with a fused fiber coupler 155. Such fused fiber couplers are described for single-mode fibers on Page G16 of the catalog of Spindler and Hoyer specified in greater detail under Fig. 20 and can be directly fused to the output of the laser fiber 5 after correspondingly precise alignment. In this case, thus, the terminator 26, 94 is connected to a passive single-mode fiber or, respectively, to a different fiber 28 and not directly to a fiber laser with the active laser fiber 5. There are also other possibilities of splitting the laser beam into a plurality of sub-beams such as, for example, beam splitter mirrors or holographic beam splitters. The advantage of the described fused fiber coupler, however, is

that the laser radiation can be brought to the processing point guided within fibers insofar as possible, this leading to a considerable simplification of the arrangement.

Fig. 16 shows the uniting of the radiation from the laser fibers 5 of two fiber lasers via a fused fiber coupler 156. The cross-sections of the two input fibers are united to form one fiber in the fused fiber coupler 156. For example, the diameter of the fibers at the two inputs of the fused fiber coupler amounts to 6 μm and the core diameter of the two laser fibers to be fused on likewise amounts to 6 μm. A core diameter of the single-mode fiber at the output of the fused fiber coupler thus becomes 9 μm, which still allows a faultless guidance of a single mode for the [appertaining]<u>corresponding</u> wavelength. The diameter at the output of the fused fiber coupler, however, can also be greater than 9 μm, and more than two outputs of fiber lasers or, respectively, fibers can be united. The terminator 26, 94 in this case is thus connected to a passive single-mode fiber or other passive fiber 28 and not to a fiber laser with the active laser fiber 5.

However, all other types of light waveguides can be welded to the fiber laser or coupled thereto in some other way, for example via optics.

One or more passive single-mode fibers or[, respectively,] one or more other passive fibers 28 can also be coupled to an individual fiber laser instead of a brancher according to Fig. 15 or a combiner according to Fig. 16, being coupled via optics in order to then connect the terminator to this single-mode fiber or[, respectively,] other fiber.

However, it is also possible to unite the outputs of a plurality of fiber lasers or single-mode fibers or other suitable fibers into which laser radiation can be coupled via wavelength-dependent or polarized beam combiners or other suitable [measures]<u>techniques</u>, and to in turn couple into single-mode fibers or other fibers that can be provided with a respective, corresponding terminator at one or both ends.

The described possibilities of branching and uniting fibers can be particularly advantageously employed when the inventive modular structure is applied to the laser radiation source.

Fig. 17 shows the principle of an acousto-optical deflector. A piezo-electric transducer 45 is applied on a substrate 161 that is also referred to as crystal, said piezo-electric transducer 45 being supplied with electrical energy from a high-frequency source 162. The laser beam 163 incident at a Bragg angle α_B is deflected out of its direction proportionably to the frequency of the high-frequency source by interaction with the ultrasound field 164 within the crystal. When the beam that is not deflected and that passes through the modulator at the moment is referenced I_0 (beam of the zero order), then the frequency f_1 yields a direction I_{11} (first beam of the first order), and the frequency f_2 yields a direction I_{12} (second beam of the first order). Both frequencies can also be simultaneously [adjacent]<u>present</u> and the beams I_{11} and I_{12} arise simultaneously, these being capable of being modulated by varying the amplitudes of the high-frequency sources. An optimum transmission efficiency for the infed radiation respectively derives when the Bragg angle amounts to half the angle between the direction of the ray beam I_0 and the direction of the deflected ray beam. For use as acousto-optical modulator, only one of the sub-beams is used. It is mostly effective for processing materials to employ the beam of the zero order because it has the higher power. However, it is also possible to use one or more beams of the first order. The energy of the beams that is not used is neutralized in that, for example, it is converted into heat on a cooling surface. Only one piezo-electric transducer 45 is provided in Fig. 17, for which reason only one laser beam 163 can be deflected or[, respectively,] modulated. However, a plurality of piezo-electric transducers can also be attached on the same substrate in order to thus simultaneously provide a plurality of laser beams, i.e. a plurality of channels, with different deflection or[, respectively,] modulation signals. The individual channels are referenced T_1 through T_n. When, as shown in Fig. 17, the acousto-optical modulator is placed into a focal point of the lens 165 and the beam path is

implemented nearly parallel through the acousto-optical modulator, the beams in the other focal point of the lens 165 are focused on the processing surface arranged here, and the beam axes between the lens 165 and the processing surface 81 proceed parallel and impinge the processing surface perpendicularly. Such an arrangement is called telocentric; the advantage is that the spacing between the beam axes remains constant when the position of the processing surface changes. This is of great significance for a precise processing of material.

Fig. 18 shows how the unused beam is neutralized. The unused beam is intercepted and deflected via a highly reflective mirror 166, which is preferably manufactured of metal for better heat elimination, is dispersed by a concave lens 75 and is directed onto an obliquely arranged plate 86 having bores 87 such that no energy can be reflected back into the laser. The plate 86 and, potentially, the mirror 166 are also cooled via a cooling system that is operated by a pump 167. It is also possible to utilize a convex lens of a glass plate instead of the concave lens. The [latter]<u>convex lens,</u> particularly when a dispersion of the ray beam to be neutralized can be undertaken with other [measures]<u>techniques</u>, which can [ensue]<u>occur</u>, for example, by special shaping of the highly reflective mirror 166, [as]<u>is</u> described under Fig. 4c. The concave lens 75 can also be omitted when one foregoes the advantage of the complete sealing of the laser gun. The plate 86 is shown with a planar surface at an angle. A plate having an arc or a cavity can also be employed. The surface can be roughened in order to absorb the laser energy well [and]<u>which is</u> conducted to the coolant.

It is advantageous for an arrangement having a plurality of tracks to arrange a plurality of such modulators on a common crystal 34 according to Figs. 19 and 19a. The individual modulators cannot be arranged arbitrarily close to one another because of too much heating. A modulator of Crystal Technology Incorporated, Palo Alto, USA, is especially suited for the inventive arrangement, this being distributed under the designation MC 80 and containing five separate deflection or[, respectively,] modulator channels. In this case, the spacing of the channels is predetermined at 2.5 mm, whereby the beam diameter is recited as 0.6

mm through 0.8 mm. A similar product by the same company is equipped with ten channels having a spacing of 2.5 mm. The spacing of the channels of 2.5 mm requires the diameter or[, respectively,] the edge length of the terminators 26, 94 is implemented smaller than 2.5 mm. When the terminator 26, 94, however, is greater in diameter or[, respectively,] in edge length than the spacing of the channels in acousto-optical deflector or modulator, an adaptation can be undertaken with an intermediate imaging, as shown in Fig. 25. Such a multi-channel deflector or[, respectively,] modulator can also be employed in the exemplary embodiments according to Figs. 4, 4a, 4b, 4c, 36, 36a and 37. Dependent on the requirement of the application, all channels need not be used. Only four channels are shown in the illustrated applied examples.

Instead of the acousto-optical modulator, however, it is also possible to utilize other modulators, for example what are referred to as electro-optical modulators. Electro-optical modulators are described under the terms "laser modulators", "phase modulators" and "Pockels cells" on pages F16 through F33 of the overall catalog G3, Order No. 650020 of Laser Spindler & Hoyer, Göttingen. Multi-channel electro-optical modulators have also been possibly employed, which is shown in the publication "Der Laser in der Druckindustries" by Werner Hülsbuch, Verlag W. Hülsbusch, Constance, page 523, Fig. 8-90a. When a one-channel or multi-channel electro-optical modulator is employed in combination with a birefringent material, then each laser beam can be split into two beams that can be separately modulated via further modulators. Such an arrangement is also referred to as an electro-optical deflector in the literature.

Fig. 18a shows an arrangement having an electro-optical modulator 168. In an electro-optical modulator, for example, the polarization direction of the laser radiation that is not wanted for processing is separated from the incident ray beam 163, and turned (P_b), and[,] subsequently, the laser radiation P_b not wanted for the processing is separated off in a polarization-dependent beam splitter, which is also referred to as polarization-dependent mirror 169, and is conducted into a sump, for example into a heat exchanger that can be composed of a cooled plate 86. The

radiation P_a wanted for processing is not turned in terms of polarization direction and is supplied to the processing surface via the lens 165. In the exemplary embodiments according to Figs. 4, 4b and 4c, the single-channel or multi-channel acousto-optical modulators 34 can be replaced by corresponding, single-channel or multi-channel electro-optical modulators. In the exemplary embodiments according to Figs. 4, 4b and 4c, the highly reflective mirror 74, 97 can likewise be replaced by the polarization-dependent mirror 169 (Fig. 18a), wherefrom an intercept arrangement 78 derives, and whereby the polarization-dependent mirror extends into the beam path [wanted]<u>desired</u> for the processing.

The fiber laser can also be directly modulated. Such directly modulatable fiber lasers that have a separate modulation input available to them are offered, for example, by IPG Laser GmbH D-57299 Burbach, under the designation "Modell YPLM Series". The advantage is that the acousto-optical modulators and the [appertaining]<u>corresponding</u> electronics for the high-frequency sources can be omitted. Moreover, the transmission unit can be simplified, as shown in Fig. 23.

Fig. 19 shows a plan view onto an acousto-optical deflector or[, respectively,] modulator. It is mentioned in the description of Figs. 4, 4b and 4c that the space 44 or[, respectively,] 111 according to Figs. 4, 4b and 4c wherein the modulators are arranged should be optimally free of those components that give off particles or gases because particles could thus settle onto the highly stressed optical surfaces, which would lead to the premature failure of the arrangement. For this reason, the electrical components of the arrangement in Figs. 19 and 19a are arranged on a separate printed circuit board 171 that merely has two arms projecting into the sealed space and produces the electrical connections to the piezo-electrical sensors 45. The printed circuit board 171 is sealed relative to the modulator housing 172, preferably with a solder location 173. The end face of the printed circuit board is preferably sealed by a metal band (not shown) that is soldered on in the region of the space 44 or[, respectively,] 111. The printed circuit board is implemented <u>in </u>multi-layer<u> fashion</u> in order to

shield the individual high-frequency channels by interposed connections to ground. Instead of a printed circuit board, some other line arrangement can also be utilized. For example, each radio frequency channel can be connected by its own shielded line. The modulator housing 172 contains an access opening 174 to the electrical components. The modulator crystal 34 can be metallized at its base area and is preferably secured on the modulator housing with a solder point or a glued connection 175. A connection 176 to a cooling system can be located directly under the fastening location in order to carry the waste heat off via the openings 87 with a coolant. The modulator housing 172 is preferably closed by a cover 177 that carries the electrical terminals 181 and also contains the connections for the cooling system, but this is not shown. A seal 43 sees to it that the modulator housing 172 is inserted gas-tight into the housing 35 or[, respectively,] 93 of Figs. 4, 4a, 4b and 4c and is secured with the connection 42.

It is possible to secure the electro-optical modulator 168 to the modulator housing (172) in a similar way and to contact it via the printed circuit board 171.

Fig. 20 indicates that the basic beam path for the exemplary embodiment of Fig. 4 for the ray beams 144 of the [appertaining]<u>corresponding</u> fiber lasers F_{HD1} through F_{HD4}. The ray beams of the fiber lasers F_{VD1} through F_{VD4} proceed partially congruently with the indicated rays but, inventively, have a different wavelength and, as can be seen from Fig. 4a, are united via a wavelength-dependent mirror 37 (not shown in Fig. 20) with the beam packet F_{HD1} through F_{HD4} to form the beam packet F_{D1} through F_{D4}. Further, Fig. 20 does not show the beam packets of the fiber lasers F_{VR1} through F_{VR4} and F_{HR1} through F_{HR4} that, as can be seen from Fig. 4a, are likewise combined via a wavelength-dependent mirror to form the beam packet F_{R1} through F_{R4}. As can be seen from the arrangement of the strip mirror 46 in Fig. 4a, the ray beams of the beam packet F_{R1} through F_{R4} in Fig. 20 would proceed offset by half a track spacing from the indicated rays. Instead of containing the indicated four ray beams, thus[,] the complete beam path contains a total of eight ray beams that yield a total of eight separate tracks on the processing surface. Fig. 20 only shows the two ray beams

144 of the fiber lasers F F_{HD1} and F_{HD4}. As already mentioned under Fig. 4, however, a plurality of tracks can also be arranged; for example, the plurality of tracks on the processing surface can also be increased to sixteen separately modulatable tracks. On the basis of a digital modulation of the respective laser, i.e. the laser is operated in only two conditions as a result of turn-on and turn-off, this arrangement enables an especially simple control and a good shaping of the processing spot on the processing surface. This digital type of modulation requires only one especially simple modulation system.

A distinction between more than 100 tonal value levels is required in high-grade multi-color printing in order to obtain adequately smooth color progressions; more than 400 tonal value stages would be optimum. When, for example, a cup in rotogravure wherein the volume of the cups determines the amount of ink applied onto the material being printed is composed of 8 x 8 or 16 x 16 small individual cups and the cup depth is kept constant, the processed surface can be quantitized into 64 or[, respectively,] 256 stages. When, however, the cup depth is controlled by additional, analog or digital amplitude modulation or by a pulse-duration modulation of the laser energy, the volume of the cups can be arbitrarily finely quantized even given a low plurality of tracks. If, for example, the cup depth were digitally controlled in only two stages, as described in greater detail under Fig. 28, a cup could be composed of 8 x 8 individual cups given eight tracks, these potentially having respectively two different depths. [I.e.]For example, the volume of the cups in this case could be quantized in 128 stages without losing the advantage of purely digital modulation, which yields a considerable advantage for the stability of the method. Given 16 tracks and 2 stages in the cup depth, the [plurality]number of digitally possible quantization stages already amounts to 512. It is also possible to generate the cups in two processing passes in order to increase the [plurality]number of tonal value [stages]steps.

The modulators 34 as well as the strip mirror 46 are not shown in Fig. 20. For a better illustration, the cross-section of the ray beam 144 from the terminator

of the fiber laser F_{HD1} that is congruent with the ray beam F_{D1} after passing the wavelength-dependent mirror is designed with a hatching. Like all other illustrations, this illustration is not to scale. The two illustrated ray beams 144 yield the processing points B_1 and B_4 on the processing surface 81 that contribute to the built-up of the processing spot 24 and generate corresponding processing tracks on the processing surface 81. The axes of the terminators 26 and of the ray beams 144 of the individual fiber lasers proceed parallel to one another in Fig. 20. The beam cones of the terminators, i.e. the shape of the ray beam 144, are shown slightly divergent. In the Figure, a beam narrowing within the lens 133 is assumed in the Figure. The divergence angle is inversely proportional to the diameter of the ray bundle in the [appertaining]<u>corresponding</u> beam narrowing. The position of the beam narrowing and its diameter, however, can be influenced by varying the lens 133 in the terminator 26, 94 and/or its distance from the fiber 28 or from the laser fiber 5. The calculation of the beam path [ensues]<u>occurs</u> in the known way. See the technical explanations on pages K16 and K17 of the general catalog G3, Order No. 650020 of Laser Spindler & Hoyer, Göttingen. The objective is that the processing points B_1 through B_n [are]<u>of</u> the processing surface 81 respectively become beam narrowings in order to obtain the highest power density in the processing points. With the assistance of the two lenses 55 and 56, beam narrowings and track spacings from the object plane 182 wherein the lenses 133 of the terminators 26 lie are imaged <u>in</u> demagnified <u>fashion</u> in an intermediate image plane 183 corresponding to the ratio of the focal lengths of the lenses 55 and 56. When, in this case, the distance of the lens 55 from the terminator 26 and from the crossing point 184 is equal to its focal length and when the distance of the lens 56 from the intermediate image plane 183 is equal to its focal length and equal to its spacing from the crossing point 184, what is referred to as a telecentric imaging is obtained, i.e. the axes of the ray bundles belonging to the individual tracks begin to proceed parallel in the intermediate image plane. The divergence, however, has been noticeably increased. The preferably telecentric imaging has the advantage that the diameters of the

following lenses 57 and 61 need only be insignificantly larger than the diameter of a ray bundle. The lenses 57 and 61 demagnify the image from the intermediate image plane 183 in a second stage onto the processing surface 81 in the described way. A preferably telecentric imaging, namely that the axes of the individual ray beams proceed parallel between the objective lens 61 and the processing surface 81, has the advantage here that changes in spacing between the processing surface and the laser gun produce no change in the track spacing, which is very important for a precise processing. The imaging need not necessarily [ensue]occur in two stages with two lenses each; there are other arrangements that can also generate parallel beam axes between objective lens and processing surface, as shown in Figures 21 and 22. Deviations in the parallelism of the beam axes between the objective lens 61 and the processing surface 81 can also be tolerated as long as the result of the processing of the material is satisfactory.

Fig. 21 shows a fundamental beam path for the exemplary embodiment of Fig. 4b. The illustration is not to scale. As was already the case in Fig. 20, the two ray bundles 144 of the lasers F_{HD1} and F_{HD4} are only a matter of a sub-set of the ray bundles of all existing lasers in order to explain the principle. In contrast to Fig. 20, however, the axes of the individual ray bundles of the terminators in Fig. 21 are not parallel but are arranged at an angle relative to one another, which is shown in greater detail in Fig. 24, and which is advantageously achieved by terminators 94 according to Figs. 10, 10a and 10b. As a result of this arrangement, the individual ray bundles 144 would cross similar to the case in Fig. 20 without a lens 55 being required. In the region of the imaginary crossing point, the dispersive lens with a short focal length, i.e. a concave lens 101 is inserted, this bending of the incoming rays off [as shown]and rendering of the ray bundles divergent is shown, i.e. widening them. The convex lens 102 is preferably arranged in the intersection of the axial rays and, together with the lens 101, forms an inverted Galileo telescope. As a result thereof, for example, parallel input ray bundles are converted into parallel output ray bundles having an enlarged diameter between the lenses 102 and 103. The desired parallelism of each input

ray bundle can, as already described, be undertaken by a suitable selection of focal length and spacing of the lens 133 from the fiber 28 or[, respectively,] laser fiber 5 in the terminators 26, 94. The objective lens 103 focuses the enlarged ray bundle onto the processing surface 81 at the processing points B_1 through B_4 that contribute to the built-up of the processing spot 24 and generate corresponding processing tracks on the processing surface 81. The imaging scale can be modified in a simple way by modifying the focal length of the lens 103. It is therefore advantageous when the lens 103 is implemented as an interchangeable objective lens. As already described, however, a vario-focusing optics can also be employed. When the position of the lens 103 is selected such that the distance between the lenses 102 and 103 corresponds to the focal length of the lens 103, the axes of the ray bundles between the lens 103 and the processing surface are parallel and yield constant spacings of the tracks of the processing surface, even given a modified between the laser gun and the processing surface.

Fig. 22 indicates the fundamental beam path for the exemplary embodiment of Fig. 4c. Like all other figures, the illustration is not to scale. The beam path is very similar to that of Fig. 21, with the difference that an arced mirror 121 is employed instead of the lens 101 and a concave mirror 115 is employed instead of the lens 102. The beam path is considerably shorter due to the folding that derives. The beam path approximately corresponds to that of an inverted mirror telescope. Mirror telescopes are independent of the wavelength which is advantageous given employment of lasers having different wavelength. The imaging errors can be reduced by employing aspherical surfaces or with an optical correction plate 117 that, however, is not shown in Fig. 22. It is advantageous from the focal length of the objective lens 112 is equal to its spacing from the concave mirror. The axes of the ray bundles are then parallel between the lens 112 and the processing surface 81 and yield constant spacings of the tracks on the processing surface, even given a modified distance between the laser gun and the processing surface. Moreover, an advantageously large spacing

of the objective lens from the processing surface derives. As described a vario-focusing optics can also be utilized.

Fig. 23 shows an arrangement having a plurality of lasers, whereby the individual laser outputs in the form of the terminators 26 are arranged on a circular segment and beam at a common cross-over point 185. This arrangement is particularly suitable for directly modulatable lasers since a very low [outlay]expense then [derives]results. In such an arrangement, the imaging on the processing surface 81 can [ensue]occur with only a single lens 186. However, an arrangement according to Figs. 4b or 4c can also be employed for imaging. The ray cones of the ray bundles from the terminators are set such that a beam narrowing and, thus, a sharp image derives for all lasers on the processing surface 81. Preferably, the spacings between the cross-over point 185 and the lens 186 as well as between the lens 186 and the processing surface 81 are of the same size and correspond to the focal length of the lens 186. In this case, the axes of the individual ray bundles between the lens 186 and the processing surface 81 are parallel and yield constant spacings between the processing tracks, even given a modified distance between the laser gun and the processing surface. Although not shown, a plurality of levels of lasers can also be arranged above one another in order to increase the power density and the power of the laser radiation source. The planes of the lasers are preferably arranged parallel to one another. As shown in Figs. 29 and 31, [but]it then derives [is]that the individual ray bundles from the individual planes meet on a spot in the processing points on the processing surface 81 and thus generate an especially high power density.

Fig. 24 shows a modification relating to Fig. 23. Four fiber lasers F_{HD1}, F_{HD2}, F_{HD3}, F_{HD4} have their terminators 94, which are described in greater detail in Figs. 10, 10a and 10b, joined to one another on a circular segment. The terminators 94 are particularly suited for joining to one another as a result of their shape. Since no directly modulatable fiber lasers are employed here, a four-channel acousto-optical modulator 34 is inserted. The piezo-electric sensors 45 can, as shown in Fig. 24, likewise be arranged on a circular segment. As shown in

Fig. 24a, however, they can also be arranged parallel as long as the ray bundles are still adequately acquired by the acoustic field of the piezo-electric sensors 45. Instead of the lens 186, a transmission unit as described in Figs. 4b and 4c is advantageously employed.

Fig. 25 indicates a demagnifiying intermediate image with the lense 191 and 192, so that the distance between the individual terminators 26, 94 can be greater than the distance between the individual modulator channels T1 through T4 on the multi-channel acousto-optical modulator 34. The imaging ratio corresponds to the relationship of the focal lengths of the two lenses 191 and 192. The intermediate image is preferably telecentrically [fashioned]designed in that the distance of the lens 191 from the lenses 133 of the terminators 26 or[, respectively,] 94 and from the cross-over point 193 is equal to its focal length, and in that the distance from the crossing point 193 to the lens 192 as well as the distance of the lens 192 from the modulator crystal 34 is equal to its focal length. By adjusting the distance between the two lenses, however, one can also achieve that the rays emerging from the lens 192 no longer proceed parallel but at an angle relative to one another in order to connect the beam path according to Figs. 21 or 22 thereto. An intermediate image according to Fig. 25 can also be employed in combination with an arrangement of the terminators on a circular segment according to Figs. 23 and 24.

The intermediate image (191, 192) is shown in Fig. 25 between the terminators (26, 94) and the modulator (34). However, a wavelength-dependent or polarization-dependent mirror 37 can also be arranged prece[e]ding or following the intermediate image in the beam direction. An intermediate image (191, 192) can also be arranged in the beam path following the modulator, before or after the strip mirror 46. Preferably, the intermediate image in the beam path is inserted at the locations referenced "E" in Fig. 4a.

Figs. 26 and 26a show how the distance between the tracks in the processing plane can be reduced. Fig. 26 is a side view and Fig. 26a is the appertaining plan view. Since the ray bundles 144 emerging from the terminators

26, 94 have a smaller diameter than the housing of the terminators, interspaces remain that are not utilized. Moreover, the minimum distances between the tracks and the maximum diameters of the ray bundles are prescribed by the multi-channel acoustic-optical modulators 34. In order to increase the distances between the tracks, a strip mirror 46 is provided that is transparent and mirrored in [alternation]alternating fashion in stripe-shaped fashion at intervals. The strip mirror 46 and the modulators are not shown in Fig. 26a. Such a strip mirror 46 is shown in Figures 27 and 27a, whereby Fig. 27a shows a side view of Fig. 27. Highly reflective strips 195 are applied on a suitable substrate 194 that is transparent for laser radiation. The interspaces 196 as well as the backside are preferably provided with a reflection-reducing layer. The ray bundles 144 from the terminators 26, 94 of the fiber lasers F_{D1} through F_{D4} pass unimpeded through the transparent part of the strip mirror 46. The ray bundles 144 from the terminators 26, 94 of the fiber lasers F_{R1} through F_{R4} are arranged such that they are reflected at the strips of the strip mirror such that that they lie in a row with the ray bundles F_{D1} through F_{D4}. The distance between the tracks has thus been cut in half.

Fig. 27b shows a strip mirror 46, whereby the substrate of the mirror was removed in the interspaces 196, and the entire, remaining surface is preferably highly reflectively mirrored, so that strips 195 derive. In this case, the strip mirrors can be preferably manufactured of metal, which is especially advantageous given high powers and the heating connected therewith.

An arrangement having strip mirrors can be combined very well with an arrangement having wavelength-dependent mirrors, as shown, for example, in Figures 4, 4a, 4b, 4c. The further beam path according to Fig. 20 can be connected vi the lens 55. The axes of the individual terminators 26, 94, however, can also be arranged at an angle, as shown in Figs. 23 and 24. In this case, the further beam path can proceed according to Fig. 21 or 22 and the lens 55 is omitted.

Figs. 28 and 28a show how fiber lasers of different wavelength, for example Nd:YAG lasers having 1060 nm and those having a different doping with 1100 nm are combined with one another via a wavelength-dependent mirror 37. The wavelength difference can be less but can also be greater.

The modulators and the wavelength-dependent mirror are not shown in Fig. 28a. Preferably, wavelength-dependent mirrors are optical interference filters that are manufactured by vapor-deposition of suitable dielectric layers onto a substrate that is transparent for the appertaining wavelengths and can have very steep filter edges as high-pass or low-pass filters. Wavelengths up to the filter edge are allowed to pass; wavelengths beyond the filter edge are reflected. Band-pass filters are also possible. Likewise, lasers of the same wavelength but a different polarization direction can be combined via polarized beam combiners, preferably polarization prisms. Inventively, a combination of polarized beam combiners and wavelength-dependent mirrors is also possible. In Fig. 28, the ray bundles 144 [emerge]emerging from the terminators 26, 94 of the fiber lasers F_{HD1} through F_{HD4} with the wavelength λ_1, pass unimpeded through a wavelength-dependent mirror 37, whereas the ray bundles F_{VD1} through F_{VD4} having the wavelength λ_2 are reflected at it and, thus, the two ray bundles are united in one another following the mirror. Each ray bundle can be separately modulated according to the invention via a respective multi-channel, acoustic-optical modulator 34. Since respectively two lasers of different wavelengths process the same track in the same processing point on the processing surface, a digital amplitude modulation in 2 stages is possible in a simple way in order, for example, to control the depth of the cups when producing printing forms for rotogravure when the two participating ray bundles are respectively merely turned on or off. However, a shared modulator for the two united ray bundles can also be employed. In this case, the modulator is arranged between the wavelength-dependent mirror 37 and the lens 55, as shown in Figs. 4, 4a, 4b, 4c. The further beam path of the transmission unit according to Fig. 20 connects via the lens 55. However, the axes of individual terminators 26, 94 can also be arranged at an

angle relative to one another, as shown in Figs. 23 and 24. In this case, the further beam path can proceed according to Fig. 21 or 22 and the lens 55 can be omitted.

Fig. 29 shows how fiber lasers with their terminators 26, 94 (Fig. 31) can be arranged in a plurality of planes. Three planes of terminators that are connected to fiber lasers lie above one another. The first track is referenced F_1 for the first plane, with F_2 for the second plane and with F_3 for the third plane. The numerals 11, 12 and 13 reference the first plane of the further tracks. The axes of the ray bundles 144 emerging from the terminators are directed parallel to one another in the individual planes. The axes of the ray bundles of the individual tracks can proceed parallel to one another, as shown in Fig. 20, or at an angle relative to one another according to Fig. 23 or 24.

In Fig. 30, the terminators 26, 94 (Fig. 31) of, for example, seven fiber lasers F_1 through F_7 are arranged in a hexagon such that the axes of their ray bundles 144 are parallel to one another. To this end, terminators according to Fig. 12 can be advantageously employed. As a result thereof, the smallest possible diameter of a common ray bundle composed of seven individual ray bundles derives.

First, Fig. 31 is a sectional view through the three planes of the first track of Fig. 29. A lens 107 collects all incoming parallel rays in its focal point 201 on the processing surface 81. As a result thereof, power and power density are multiplied by the plurality of lasers united in the focal point, i.e. are tripled given three planes. When the axes of the ray bundles emerging from the terminators 26, 94 proceed parallel to one another for tracks and planes, the ray bundles of all tracks would likewise be additionally united in the focal point, and a common processing point would arise on the processing surface that generates a processing track. I.e., the same number of processing tracks are registered next to one another as there are tracks of terminators. The power of the ray beams of the various planes is superimposed in the respective processing point and the power density is tripled in the illustrated example. The individual fiber lasers can thereby be directly modulated; however, external modulators can also be

employed. Figs. 32 and 33 describe how a multiple-channel acousto-optical modulator corresponding to the [plurality]<u>number</u> of tracks can be preferably employed for the simultaneous modulation of all ray bundles of the various planes.

Fig. 31 is also a sectional view through the bundle arrangement according to Fig. 30. It is known that parallel ray bundles that are incident into a lens have a common focus. Page 13, Fig. 2.21 in the book “Optik und Atomphysik” by R. W. Pohl, 13th edition, 1976, Springer Verlag shows such an arrangement. Further, DE-A-196 03 111 discloses an arrangement wherein, as can be seen from Fig. 1 therein, the radiation from a plurality of laser diodes is respectively coupled into a single-mode fiber, the radiation at the output of each fiber is collimated to a respective, parallel ray bundle, and all parallel ray bundles are directed onto a common spot with a shared lens in order to achieve an increased power density. Compared to the arrangement shown in Fig. 31 with fiber lasers, however, this arrangement has serious disadvantages. When[, namely,] radiation is to be efficiently coupled into single-mode fibers, single-mode laser diodes are required for this purpose so that the aperture of the single-mode fibers is not overfilled and the total radiation can be transmitted into the core of the single-mode fiber. Single-mode laser diodes, however, can only be manufactured with extremely limited power because the loadability of the minute laser mirrors represents a technological barrier. Single-mode laser diodes are therefore only available up to an output power of approximately 200 mW and are far more expensive per watt then multi-mode diodes that are offered with radiation powers of up to several kilowatts. Given single-mode fibers for 800 nm wavelength, the product of core diameter and numerical aperture amounts to approximately 5 μm x 0.11 = 0.55 μm, whereas this lies at 300 μm x 0.4 = 120 μm given a fiber laser having a typical diameter of the pump fiber of 300 μm and a numerical aperture of 0.4, which amounts to a factor of 220. When the area ratio of the two fibers is considered, then a factor of $(300/5)^2 = 3600$ derives. Even when a reduction of the laser radiation by the factor of the absorption efficiency of approximately 0.6

is assumed given the fiber laser, this being the efficiency with which the pump radiation is converted into laser radiation, the power of the laser radiation that can be achieved at the output of a fiber laser is several orders of magnitude higher then the power at the output of a single-mode fiber. Even if single-mode diodes or other laser radiation sources having very high power were available, it would nonetheless not be possible to couple this satisfactorily into single-mode fibers, since the fibers would burn given the slightest misadjustment at the fiber entry. This problem does not exist given fiber lasers since a relatively large fiber diameter is available for the pumping and the energy is transmitted into the single-mode core of the laser fibers only within the laser fiber, which is possible unproblemmatically and with good efficiency.

The lens 197 in Fig. 31 unites the entire power of all seven ray bundles F_1 through F_7 of the corresponding fiber lasers in its focal point 201 which represents the processing spot 24 on the processing surface 81. The power and the power density in the focal point thus become higher by the factor of 7 than is the case given an individual ray bundle. When, for example, 100 W are required in order to generate a required power density on the processing surface, then seven lasers having a radiant power of approximately 15 watts each suffice in this case. However, more than seven lasers can be provided. The lasers can preferably be directly modulated. However, it is also possible to modulate all seven ray bundles separately or overall with an external modulator or to supply a plurality of such bundle arrangements to a multi-channel modulator in such a way that the modulator channels are preferably arranged in the focal point of a uniting lens 197 that is allocated to each bundle. It is also possible to couple the multiplied power of each and every bundle into fibers before or after the modulation. Further, such bundle arrangements can be advantageously utilized in laser guns according to Figs. 4, 4a, 4b, 4c.

It is advantageous to separately modulate the individual lasers. This is especially suitable when a high number of lasers is employed, since, for example, a quantized modulation that is similar to an analog modulation, a quasi-analog

modulation of the united laser radiation is then enabled by digital modulation of the individual lasers. However, it is also possible to modulate the ray bundles 144 of all lasers in common, for example with an acousto-optical modulator. In this case, the ultrasound field of the modulator cell must exhibit such a size that the overall ray bundle shown in Fig. 30 can be modulated. However, the switching time of the acousto-optical modulator becomes so great as a result thereof that the shape of the cups to be engraved is disturbed as a consequence of the rotational movement of the drum containing the processing surface. However, it is possible to entrain the laser beam with a deflection motion in the direction of the rotary motion of the printing cylinder to be engraved during the engraving and to thereby achieve a processing spot 24 that is stationary on the processing surface. Inventively, the deflection motion can [ensue]<u>occur</u> with the same acousto-optical modulator with which the amplitude modulation [ensues]<u>occurs</u>. However, another acousto-optical cell can also be utilized, the deflection [ensuing]<u>occurring</u> therewith.

Fig. 32, in a farther-reaching example, shows how the power density on the processing surface can be considerably increased by providing terminators 26, 94 with the [appertaining]<u>corresponding</u> fiber lasers in a plurality of planes, but a modulation of all ray bundles 144 belonging to a track can be simultaneously implemented with a single-multi-channel, acousto-optical modulator 34 corresponding to the plurality of tracks. In this example, the terminators are arranged in three planes of n tracks each that lie above one another. The power of all ray bundles 144 of all planes should be largely focused in a processing point in the processing surface for each track in order to achieve a high power density. The terminators 26, 94 are arranged parallel to one another in tracks and planes, [in that]<u>since</u> the terminators 26 are joined to one another in close proximity. As shown, terminators having a round cross-section can be employed for this purpose; preferably, however, terminators having a quadratic cross-section according to Figs. 9 and 9a are utilized. Given the parallel arrangement of the tracks, the illustrated imaging system having the cylindrical lenses 202 and 203,

also refer to as cylinder optics, can, for example, be added analogous to an arrangement like that of Fig. 4. When the individual tracks are to proceed at an angle according to Figs. 23 or 24, terminators 94 according to Figs. 10, 10a and 10b are preferably employed. In this arrangement, too, the ray bundles of the individual planes remain parallel; the fits of the terminators 94 should proceed parallel in the side view of Fig. 10a for this purpose. When the axes of the ray bundles for the tracks proceed at an angle relative to one another, the cylinder optics having the lenses 20[3]2 and 203[[sic]] can be added, for example analogous to the arrangements according to Figs. 4b or 4c. The ray bundles 144 emerging from the terminators are directed onto the convex cylinder lens 202 that would ignite the rays in its focus to form a line having the length of the beam diameter. A concave cylinder lens 203 having a shorter focal length then the cylinder lens 202 is attached such in the region of the focus of the cylinder lens 202, 203 having a long focal length such that its focus coincides with the focus of the cylinder lens 202. As a result thereof, the rays that leave the lens 203 become parallel again. The spacings between the individual planes, however, have been reduced by the ratio of the focal lengths of the two cylinder lenses compared to the spacings that the ray bundles had when they left the terminators 26, 94. The spacings of the ray bundles have remained unmodified in the direction of the tracks since the cylinder lenses exhibit no refractive effect in this direction. As a result thereof, elliptical beam cross-sections derive in the modulator. The purpose of this arrangement is to make the overall height of the three ellipses lying above one another so small that it approximately corresponds to the major axis of the ellipses in order to create conditions in the channels of the acousto-optical modulator similar to those achieved given a round beam cross-section so that, for example, similarly short switching times can be achieved.

Fig. 33 shows that, however, the spacing of the two cylinder lenses can also be modified somewhat so that all three elliptical ray bundles overlap in the modulator, this is in fact yielding a shorter switching time in the acousto-optical

modulator but also yielding an increased power density in the modulator crystal. The cylinder lens 203 can also be omitted for this purpose.

The cylinder optics (202, 203) is shown in Fig. 25 between the terminators (26, 94) and the modulator [(]3[4)]. However, a wavelength-dependent or polarization-dependent mirror 37 can also be arranged preceding or following the cylinder optics in beam direction. A cylinder optics (202, 203) can also be introduced in the beam path following the modulator, preceding or following the strip mirror 46. Preferably, the intermediate image is inserted in the beam path at the locations references "E" in Fig. 4a.

For removing the material eroded from the processing surface, Fig. 34 shows a mouthpiece 82 whose main job is to use a directed flow to see to it that optimally no clouds of gases and/or eroded material form in the optical beam path between objective lens and processing service 81, these clouds absorbing a part of the laser energy and depositing on the processing surface and thus negatively influencing the work result.

As a result of its specific shaping, the mouthpiece 82 prevents the described disadvantages. Preferably, it is secured to the laser gun with connections 204 that are simple to release, so that it can be removed and [claimed]<u>cleaned</u> in a simple way and also enables a simple cleaning as well as a simple replacement of the objective lens (not shown) 61, 103, 112. A cylindrical bore 206 for adaptation to the objective lens and a preferably conical bore 207 as passage for the ray bundle as well as another preferably cylindrical bore that represents the processing space 211 are located in a preferably cylindrical base member 205. The distance of the base member 205 from the processing surface 81 should not be excessively great. The processing points (not shown) for producing the individual processing tracks on the material to be processed lie in the processing spot 24. A broad, all around extraction channel 212 is preferably located in the base member, this channel 212 being connected to the processing space 211 via a plurality of extraction channels 213 that should have a large cross-section. Preferably, 3 through 6 extraction channels 213 are present. A further,

preferably all around admission channel 214 is located in the base member, this channel 214 being connected via nozzle bores 215 to the processing space 211 and to the conical bore 207 via smaller bypass bores 216. 3 [through]to 6 nozzle bores 215 and 3 [through]to 20 bypass bores 216 are preferably distributed over the circumference of the admission channel 214. All bores can be offset relative to one another and relative to the extraction channels 213 on the circumference. Further bypass bores can also be attached and directed onto the objective lens. This, however, is not shown. The base member is surrounded by a ring 217 applied gas-tight that contains a plurality of extraction connectors 221 in the region of the channel 212 to which extraction hoses are connected, these being conducted via an extraction filter to a vacuum pump. [E]The extraction hoses, the extraction filter and the vacuum pump are not shown in Fig. 34. In the region of the channel 214, the ring contains at least one admission connector 222 via which compressed air filtered with an admission hose is supplied. The quantity of admitted air can be set [such]with a valve such that it is just adequate in order to adequately rinse the processing space and such that it generates a slight air stream along the conical bore via the bypass bores that largely prevents a penetration of particles into the conical bore. [A]The admission hose, the valve and the filter are not shown in Fig.3 4. The nozzle bores 215 are directed such onto the processing spot 24 such that the clouds of gas, solid and molten material arising in the processing are quickly blown out of the beam path so that these absorb as little laser energy as possible and cannot negatively influence the processing result. Oxidation-promoting or oxidation-inhibiting gases or other gases can also be blown in with the admission air, these having a positive influence on the processing process. A slight quantity of air from the environment co-flows through the processing space to the extraction channels through the gap between the processing surface and the base member 205; this, however, is not shown. The filter in the extraction line is attached easily accessible in the proximity of the mouthpiece and sees to keeping the vacuum pump clean. It is also possible to introduce the filter directly in the extraction channel 212. As described under Fig.

39a, it is useful when a protective atmosphere is additionally conducted over the objective lens. If the mouthpiece 82 becomes too hot due to the laser radiation reflected from the processing surface and the air that flows through does not suffice for cooling, then the mouthpiece can be provided with additional bores through which a coolant is pumped; this, however, is not shown in the Figs. A glass plate 218 that is highly anti-bloomed on both sides and is simple to change can also be located within the cylindrical bore 205, this glass plate 218 keeping dirt particles away from the objective lens[t]. The shape of the mouthpiece can also deviate from the form that is described and shown. For example, the bores need not be cylindrically or conically implemented, as described; they can be varied in shape. Likewise, for example, the nozzle bores and extraction channels can assume arbitrary shapes and can also be asymmetrically arranged. For example, the nozzle bores in Fig. 34 can be arranged more in the upper part of the Fig., whereas the extraction channels lie more in the lower part of the Figure. For example, the nozzle bores and/or the bypass bores can also be foregone. The shape of the mouthpiece can also be modified, particularly when the shape of the processing surface and the type of relative motion between processing surface and laser radiation source demand this. It is conceivable to utilize a modified form of the described mouthpiece when the material to be processed is located, for example, on a planar surface instead of on a drum surface, and the laser radiation is conducted past this line-by-line. In this case referred to as flatbed arrangement, which is shown in greater detail in Figures 43, 43a and 43b, the mouthpiece is implemented elongated corresponding to the line length and is provided with an elongated processing space corresponding to its length. The mouthpiece is equipped with nozzle bores and extraction channels from one or from both sides. In this case, the glass plate would be given a rectangular shape and would extend over the entire length of the arrangement. In this case, Figure 34 could be analogously considered as a cross-section of the elongated mouthpiece. Even when the material to be processed is located in a hollow cylinder, which is not shown in detail in Figs 44a and 44b, a similar mouthpiece can be produced in that

the mouthpiece described for the flatbed arrangement is adapted in the longitudinal direction[such] to the shape of the hollow cylinder such that a slight gap between the processing surface and the mouthpiece derives over the entire length. The glass plate would be given a rectangular shape in this case and would be curved over the entire length of the arrangement.

In a known scraper device that, however, is not shown in the figures can be located in the proximity of the mouthpiece but need not necessarily be connected to it or to the laser gun. For example, the job of the scraper device is to scrape off the ejects arising at the edges of the cups during the processing process at rotogravure forms. Further, a brush device (not shown) can preferably be located in the proximity of the laser gun, this brushing out the cups that have been cut and ridding them of adhering dirt. Further, a measuring device (not shown) can be preferably inventively located at the laser gun, this measuring the position and/or the volume of the cups immediately after they are produced. In contrast to cups that have been manufactured by electro-mechanical engraving or with a single laser beam, the volume can be inventively more precisely identified for cups that are produced with the inventive laser radiation source and have steep edges and constant depth, in that the area of the cup is determined with a specific, fast camera and the volume is derived therefrom. It is thereby advantageous to measure a series of cups in order to reduce measuring errors. It lies within the framework of the invention that specific control fields are engraved in a region of the rotogravure cylinder, this being provided for monitoring measurements and/or for monitoring prints. A rated/actual comparison can be produced with this measured quantity for the generated cups and with the cup size prescribed for this location. The result can then be employed in order to correct the position and/or the volume of the subsequently produced cups.

Fig. 35 shows the conditions on the processing surface. The processing points are identified with the indices that indicate the ray bundles of the fiber lasers according to Figs. 4, 4a, 4b and 4c that produce them. For example, the ray bundles of the fiber lasers F_{VR1} and F_{HR1} generate the processing point $B_{FVR1+FHR1}$ in

common to the diameter of the processing points is referenced B, and their spacing is referenced A. In the multi-channel, acousto-optical modulator described under Figs. 19 and 19a, the allowable diameter of the ray bundle 144 is smaller than the spacing of the channels of the modulator. The diameter of the ray bundle 144 in the terminators 26, 94 can also be made just as large as the outside diameter of the terminators without great [outlay]expense. It follows therefrom that A is thus greater than B. This leads to undesired interspaces at the processing tracks 224 that derive as a result of the relative motion between the material to be processed and the laser gun. The processing tracks have a track width D that [correspond [sic]]corresponds between the diameter of the processing points B and R[[sic]] referenced 1 through 8 in Fig. 35. In order to reduce these interspaces, two beam packets were already nested inside one another with the strip mirror, as described under Figs. 4, 4a, 26 and 26a, in order to cut the interspaces in half. In order to reduce the remaining interspaces even more, or to entirely avoid them or cause the processing tracks 224 to overlap, the laser gun can be turned such compared to the relative motion direction between the material to be processed and the laser gun such that the tracks come closer to one another, this being shown in Fig. 35. In order, for example, to achieve a spacing C of the processing tracks 224 that is equal to the diameter B of the processing points, the laser gun must be turned by the angle β according to the relationship $\cos \beta = B/A$. Distortions in the image information arise on the processing surface due to the rotation of the laser gun, since the starts in the individual processing tracks are now shifted relative to one another. These distortions, however, are already compensated in the editing of the processing data. It is also possible to undertake this compensation by an adjustable, different delay of the signals in the individual data channels immediately before the modulation or to simply accept the distortions. Further possibilities for setting and reducing the spacings of the processing tracks are presented in Figs.36, 36a, 36b, 36c and 37.

Fig. 36 shows the principle of how processing points $B_1 ... B_4$ derive on the processing surface 81 when the individual channels are charged with different

frequencies f_1 through f_4 in a multi-channel acousto-optical modulator 34 having four separate channels. For example, the modulator channel T_1 (Fig. 36a) is thereby supplied with a frequency f_1, whereby f_1 is provided with a higher frequency compared to f_4 in the modulator channel T_4 (Fig. 36a), so that a greater spacing of I_0 derives for the processing track 1 than for the processing track 4. The channels T_2 and T_3 are provided with corresponding frequencies f_2 and f_3 in order to achieve the illustrated arrangement of the processing tracks 224. However, the frequencies can also be arranged such that the frequency f_1 is lower then the frequency f_4. It is also possible to arbitrarily allocate the frequencies f_1 through f_4 to the individual modulator channels T_1 through T_4. In this case, a lens 165 as shown in Fig. 17 and Fig. 36a is not absolutely necessary; rather, the laser radiation emerging from the terminators can be focused such that a sharp image derives in the processing points on the processing surface.

How the ray bundles focused by the lens 165 impinge the generated line M of the drum is shown in Fig. 36a with reference to an example (not to scale) with <u>the </u>rotating drum on which the processing surface 81 lies. The position of the puncture points P of the ray axes with the plane of the lens 165 thereby corresponds to the principle of Fig. 36. [To]<u>For</u> that [end]<u>purpose</u>, the modulator 34 with the channels T_1 through T_4 is correspondingly arranged relative to the ray bundles 144 of the fiber lasers F_1 through F_4. What is achieved by a suitable selection of the frequencies f_1 through f_4 is that the partial rays that generate the processing points B_1 through B_4 lie at desired distances from one another in the direction of the generated line M. This has the advantage that the position of each processing point and, thus, of each processing track 224 can be individually set by adjusting the [appertaining]<u>corresponding</u> frequency. A particular advantage of the arrangement derives when, as indicated in Fig. 17, the multi-channel acousto-optical modulator is arranged approximately in the one and the processing surface is arranged approximately in the other focal point of the lens 165<u>,</u> and the axes of the ray bundles of the fiber lasers F_1 through F_4 are arranged approximately in parallel planes. The processing points B_1 through B_4 then lie in a row on the

generated line M (36a), and the axes of the partial rays that form the processing points are parallel and reside perpendicularly on the processing surface (Fig. 17). Another advantage of the arrangement is [comprised therein] that the Bragg angle for optimizing the efficiency can be individually set for each modulator channel, but this is not shown in the Figures. In this example, the deflected rays are used for processing material, whereas the non-deflected rays I_0 are blanked out by an intercept arrangement similar to that shown in Figure 18. In contrast to the arrangement in Figure 18, it is shown here that the mirror 166 acting as intercept arrangement can also be arranged between the lens 165 and the processing surface. As described under Fig. 4, however, the intercept arrangement can also be foregone when a symmetrical or asymmetrical defocussing reduces the radiation that is contained in I_0 and is unwanted for processing in terms of its power density to such an extent that no processing effect is produced when it is directed onto the processing surface.

Fig. 36b shows an expanded embodiment of Fig. 36a in a side view. The lenses 202 and 203 are inserted between the multi-channel modulator with the channels T_1 through T_n, said lenses 202 and 203 being preferably cylinder lenses and forming a cylinder optics, as described under Fig. 32 and Fig. 33. This cylinder optics [[...] demagnified]demagnifies the distance between the channels T_1 and T_n at the location of the lens 166 and, given a predetermined focal length of the lens 165, thus, the angle at which the rays of the individual channels T_1 through T_n impinge the processing surface,[which] is particularly significant given a great number of channels and significantly favors the costs for the lens 165, which can also be a system composed of a plurality of lenses, as well as its makeability.

Fig. 36c shows a plan view relating to Fig. 36b, from which it can be seen that the cylinder optics exhibits essentially no effect in this view. The ray bundles F_1 through F_n coupled into the acousto-optical modulator 161 are in fact shown under the same Bragg angle; however, they can also, however, be coupled in individually differently under the respectively optimum Bragg angle.

Fig. 37 emphasizes another advantage of the arrangements according to Figs. 36, 36a, 36b and 36c, namely that respectively two processing points B_{11}, B_{12} through B_{41}, B_{42} can now be generated instead of the processing points B_1 through B_4 by simultaneous application of two different frequencies to the respective modulator channels. Instead of four processing tracks, eight separately modulatable processing tracks 224 have now arisen without increasing the number of lasers and/or the number of modulator channels. It lies within the scope of the invention to also employ more than two frequencies per modulator. Twelve different frequencies with a single modulator channel have already been realized for a similar purpose. Another advantage in the generation of processing points with acousto-optical deflection is the possible shift of the processing points at high deflection speed. By modifying the applied frequencies, individual or all processing tracks 224 can be very quickly displaced relative to their previous position and there is thus a further possibility of beneficially influencing the position and shape of the cups. With this [measure]<u>technique</u>, in particular, the position of the processing tracks can be correspondingly readjusted to a rated quantity with high precision. Precisions of a fraction of a track width are thereby possible. Inventively, the actual position of the individual processing tracks can be precisely determined with a known, interferometrically functioning measuring system in that, for example, the actual position of the laser radiation source is registered during the processing event and a correction signal for the required displacement and readjustment of the processing tracks is generated by comparison to the rated position of the processing tracks. This can be of interest particularly when a seamless join<u>t</u> is to be made to a processing pattern that already exists or when a pattern that already exists is to be post-processed. Another enormous advantage of the arrangement is[comprised therein] that the Bragg angle can be individually set for optimizing the efficiency for each modulator channel, which, however, is not shown in the Figures. Up to now, acousto-optical arrangements wherein a plurality of sub-beams are generated from a laser beam by applying a plurality of frequencies [and]<u>wherein</u> all of these have

a shared Bragg angle for all sub-beams, has not yet made a breakthrough in processing of materials because the efficiency is too low. When, however, a combination of a [plurality]number of laser beams having respectively individually set Bragg angle and a [plurality]number of acousto-optically generated sub-beams per laser beam is selected as proposed, then a clearly higher efficiency can be achieved, so that a great plurality of simultaneously acting processing tracks can be realized for processing material.

As described under Figs. 18 and 18a, however, single-channel or multi-channel electro-optical modulators can also be utilized in conjunction with a birefringent material in order to split each laser beam into two beams that can be separately modulated via further electro-optical or acousto-optical modulators.

It has been emphasized that the processing of the material in Figs. 36, 36a, 36b, 36c and 37 should [ensue]occur with the deflected laser beams and that the radiation contained the non-deflected ray laser beam is to be neutralized, so that no processing effect is produced. This, however, is not absolutely necessary, and instances are conceivable wherein one works conversely. A further advantage of the arrangement shall therefore be cited and explained with reference to Fig. 36a[:] wherein one wishes to employ the radiation contained in the laser beams I_0 for processing material, the mirror 166 is removed. The entire radiant power from all four lasers F_1 through F_4 thus derives[[sic]] on the generated line in a spot. More than four times the power density thus derives in the spot compared to the previous processing points B_1 through B_4, and it can be assumed that no processing effect arises in B_1 through B_4 given specific materials and process parameters. Ie., the processing surface simultaneously serves as a sump for the radiation that is not intended to produce any processing effect. This is advantageous since a thermal equilibrium occurs on the processing surface since the entire laser energy is supplied to the processing surface in every case. It lies within the scope of the invention that fewer or more than four lasers with [appertaining]corresponding modulator channels are utilized and that the difference in the power density between the radiation that is intended to produce a

processing effect and the radiation that should not produce any processing effect is increased per modulation channel by employing more than one frequency per modulator channel. It also lies within the framework of the invention that the described principle can be advantageously applied when the laser beam incident into the acousto-optical modulator has high divergence, as is the case, for example, when the acousto-optical modulator in an arrangement according to Fig. 31 is to be arranged in the proximity of the focal point 201 or in arrangements wherein the laser has an especially great divergence. In Fig. 31, for example, the axis of the ray bundle emerging from the laser F_2 is intended to represent the position of the optimum Bragg angle for a specific frequency. In this case, the Bragg condition is met far more poorly for the one frequency for the rays at the edge of the ray bundle, for example of the lasers F_1 and F_3, than for the central rays of, for example, the laser F_2, and only a slight part of the radiation is deflected, which means low contrast for the modulator. When, however, a plurality of frequencies are simultaneously applied to the acousto-optical modulator and when these frequencies are selected such that they are optimum both for the outer as well as for the middle incident ray bundle with respect to the Bragg angle, the highest possible contrast derives and the highest possible difference in the power density arises on the processing surface between the radiation that is intended to produce a processing effect and the radiation that should not produce any processing effect.

Fig. 38 shows how [dexterous]<u>a flexible</u> arrangement of the components in the optical beam path can see to it that the laser ray bundles never perpendicularly impinge the optical surfaces. This prevents a part of the radiation from being reflected from these surfaces back into the lasers. When[, namely,] energy proceeds back into a laser, an excitation occurs in the laser and the laser begins to oscillate in terms of the amplitude of the radiation that is output. The output power is thus no longer constant and patterns are formed in the process surface that can make the result unuseable. Fig. 38 shows the axial rays of two planes; the lasers, however, can also be arranged in one or more planes as long as

the symmetry axis for the two axes that are shown is not used. For reasons of function, the acousto-optical modulator is already turned by the angle α_B. In order, however, to be certain that energy is not reflected back into the laser as a consequence of the changing ultrasound field, the modulator can be additionally turned by the angle γ, as shown in Fig. 38. Another possibility for avoiding oscillations of the laser is the insertion of one or more optical components at suitable locations in the beam path that only allow laser radiation to transmit in one direction. For example, what are referred to as Faraday isolators can be employed for this purpose, as described under Fig. 20 in [said]<u>the</u> catalog of Spindler and Hoyer on page F2. Such isolators are not shown in the Figures.

Fig. 39 shows a lens 101 whose mount contains bores 87 that preferably surround the lens in a plurality of turns and have a coolant flowing through them. Given high-power arrangements, the absorption of the optical medium of the lenses can be left out of consideration. Moreover, a slight part of the radiation is dispersed by every optical surface even given the best anti-blooming and is absorbed by the mount parts. A cooling of the lens mounts is therefore meaningful. It has already been mentioned that materials having high thermal conductivity and low absorption such as, for example, sapphire are advantageous for the most stressed lenses. Sapphire also has the advantage that the lens surface does not scratch when cleaning due to the greater hardness of the material. One should also see to a good contacting of the optical medium with the mount. This is advantageously achieved by a metallization of the edge zone of the optical element and by a soldering 223 to the mount. Metallic solders [...] a better heat conduction than glass solders.

It is also possible to cool the critical component parts of the laser gun 23 and of the pump source 2 with the assistance of what are referred to as micro-channel coolers, as described in the article "Lasers in Material Processing" in the publication SPIE Proceedings, Vol. 3097, 1997.

Fig. 39a shows a section through an inventive mount 118 for the objective lens 61, 103, 112 that, for example, is secured with a thread to the tube body 95,

96 or to the mount 116 and is sealed with a seal 125. The objective lens can be glued into the mount or, preferably can be metallized at its edge and soldered into the mount. The mount can be provided with one or more bores 120 through which a protective atmosphere that comes from the interior of the optical unit 8 flows and, for example using a channel 119, is conducted via the side of the objective lens 61, 103, 112 pointing toward the processing surface in order to prevent a contamination of the objective lens by particles of material or by gases that are released during the processing.

Fig. 40 describes a further possibility for preparing fiber lasers or optical fibers, preferably single-mode fibers, for an arrangement in tracks and planes with small spacing. The fiber 28 or[, respectively,] laser fiber 5 is ground on all sides at the last end to such an extent that a side length arises that is reduced to such an extent that the exit points of the laser radiation 13 lie at a required, slight spacing. In this case, the terminators 26, 94 can be omitted, and an especially simple structure derives. The surfaces that reside opposite can thereby proceed in pairs parallel to one another or at an angle, or one pair proceeds parallel and the other pair proceeds at an angle relative to one another, as was already described for the terminators under Figs. 9 and 10.

Fig. 40a shows a plan view onto, or[, respectively,] a cross-section through the ground laser fiber. The cross-section can preferably be rectangular or quadratic; however, it can also have all other shapes.

Fig. 40b shows a side view of the fiber bundle wherein the fibers were processed similar to Fig. 40, so that the axes of the individual ray bundles 13 proceed nearly parallel.

Fig. 40c represents a side view of the fiber bundle wherein the fibers were processed wedge-shaped, so that the axes of the individual ray bundles 13 intersect outside the fiber bundle.

Fig. 40d again shows a side view of the fiber bundle wherein the axes of the individual fibers in fact proceed parallel but the exit faces of the individual

fibers are arranged at different angles ε relative to the fiber axis, so that the axes of the individual ray bundles 13 intersect within the fiber bundle.

Fig. [41shows]41 shows how a receptacle with four tracks can be produced from ground fibers or laser fibers according to Fig. 40 and Fig. 40a, Fig. 40b, Fig. 40c, 40d. A receptacle in a plurality of planes is shown in broken lines in Fig. 41 in the form of two further planes. The receptacle is also not limited to four tracks and three planes; the laser outputs can be arranged in an arbitrary [plurality]number of tracks and planes according to this principle. On the basis of a corresponding shaping when grinding the fibers, it is possible to determine the spacings between the exit points of the laser radiation 13. For example, the spacing can be implemented such that the laser radiation of the individual plans overlaps [such]on the processing surface 81 such that only tracks derive or such that the individual tracks overlap [such]so that only planes derive. The spacings between the exit points of the laser radiation 13, however, can also be selected such that the laser rays of all tracks and all planes overlap in a point on the processing surface. [To]For this [end]purpose, the fiber lasers or optical fibers can also be arranged in a bundle.

The principle of the described arrangement of laser outputs in a plurality of planes or in a plurality of tracks or in a plurality of tracks and in a plurality of planes or overlapping in a point also inventively applies to the laser rays incident on the processing surface 81. A plurality of tracks or a plurality of levels or a plurality of tracks and a plurality of levels of laser beams can likewise be arranged on the processing surface according to this ordering principle or the laser beams can be arranged overlapping in a point.

The arrangement according to Figs. 40, 40a, 40b, 40c, 40d and 41 is particularly suited for directly modulatable lasers. However, external modulators can also be employed. The emerging ray bundles can be imaged into the processing surface with the known arrangements; however, a receptacle can also be implemented, whereby the ray bundles are directly directed onto the processing surface, i.e. without transmission unit, in that, for example, the outputs of a laser

radiation source according to Fig. 41 are brought extremely close to the processing surface or lie on the surface of the material in sliding fashion, this yielding an especially simple arrangement. Such a method can be employed, for example, when convergence in the surface of the material are to be excited by energy irradiation or when a material transfer is to be undertaken. In the example of a material transfer, a thin film is placed onto the material to be provided with images that, for example, can be a printing cylinder, an offset plate, an intermediate carrier or the material to be printed itself, a layer being applied to the underside of said thin film that faces to the material to be provided with images and that is stripped by energy irradiation and can be transferred onto the material to be provided with images.

Fig. 42 shows another embodiment of the laser radiation source that can be employed for multi-channel cutting and incising of, for example, semiconductor materials and as [[...]]<u>disclosed</u> in German Patent Application P 198 40 936.2 of the assignee "Anordnung zum mehrkanaligen Schneiden und Ritzen von Materialien mittels Laserstrahlen" running parallel with and filed simultaneously with the present patent application. The terminators 26, 94 of the fibers or, respectively, fiber lasers F_a through F_n have ray bundles 144 that are focused with the lens 133 at a predetermined distance from the terminator. The diameter of the processing points B_a through B_n amounts, for example, to 20 µm; however, it can also lie thereabove or therebelow. Further, the terminators are arranged [such]on a profiled rail 256 described in greater detail in Figs. 42 and 42b<u> such</u> that their mutual spacing "A" can be set to arbitrary values until the terminators meet one another. The profile rail is preferably secured to an arm of a robot (Fig. 42c) and can, for example, be moved in the directions x, y, z relative to ta table 225 with actuating drives that are shown in Figure 42c. Moreover, the profiled rail can be turned relative to the table by an angle φ having the axis z' (Fig. 42c), which can also be utilized for determining the mutual spacing of the processing tracks. In the exemplary embodiments according to Figs. 4, 4b, 4c, 43, 44, the laser gun is turned around the axis of the tube 51, 95, 113 in order to vary the spacings

between the processing tracks. Further, the table can be moved in the directions x, y, z and can be turned by an angle φ with the axis z. The material to be processed, for example one or more, what are referred to as "wafers" separated from a drawn semiconductor ingot, can be secured on the table 225 with clamp or suction devices (not shown). For example, fine, parallel tracks as needed, for example, for contacting photo-voltaic cells, can be incised into the semiconductor material with the laser energy in the individual processing points B_1 through B_n. However, fine bores can also be introduced into the semiconductor material or it can be cut with the laser in order, for example, to thus separate electrical circuits from one another. An inventive arrangement for removing the material 249 (Fig. 42c) eroded from the processing surface is attached close to the processing surface 81 for each processing track 224 separately or for a plurality of processing tracks 224 in common, the functioning of said arrangement being described in detail in Fig. 34. When the profiled rail with the terminators is turned relative to the table in order to modify the spacing between the processing tracks, it is inventively expedient to compensate the distortion of the pattern to be registered that arises due to the relative rotation by a pre-distortion of the pattern to be applied and/or to compensate it with a time control of the data stream. On the basis of the turning, it is also possible to intentionally [demonstrate [sic]]provide different line spacings given relative motions in x-direction and in y-direction. [Further]For contacting of the photo-voltaic cells, for example, two different line patterns are required: a first pattern wherein the incised lines following the metallization produce the contact to the semiconductor material should have spacings of a few millimeters between the individual lines and should, for example, proceed in the x-direction. Further, what are referred to as bus bars are required that proceed at a right angle relative to the contact lines and connect these to one another. These lines forming the bus bars should, for example, proceed in the y-direction and lie close to one another so that they act like a closed band following the metallization. Inventively, such a pattern can be very simply manufactured in that the profiled rail with the terminators is turned to such an extent until the desired pattern

[derives]results. Due to the parallel arrangement of a plurality of fiber laser outputs, the time required for the processing can be considerably shortened; for example, ten laser outputs can be employed in parallel for the incising of the photo-voltaic elements 10, this increasing the output by the factor of 10.

The described arrangement for cutting and incising is not only suitable for processing semiconductor materials but can be employed for all materials wherein the precise production of patterns is important such as, for example, in manufacturing printing forms.

Fig. 42a and the [appertaining]corresponding sectional view of Fig. 42b show how the terminators 26 of the individual fiber lasers F_a through F_n are secured. The profiled rail 256 is secured to a carrier 260 with connections 261, [said]the carrier potentially being, for example, the arm of a robot. The terminators 26 are accepted in mounts 257 and fixed with screw 259. The mounts 257 are provided with a profile mating with the profiled rail 256, are placed in a row onto the profiled rail 256, are set at predetermined intervals "A" from one another and are fixed with the screws 259. Due to an inventively small structure of the terminators 26 and of the mounts 257, a very slight spacing"A" is possible. The profiled rail with the terminators can be conducted across the processing surface with the robot for the purpose of processing the material, as shown in Fig. 42 and described in detail. The required movements for producing the processing tracks can be executed by the table 225 described in Fig. 42 that can also be carried out by the arm of the robot. Preferably, the arm of the robot can also undertake a rotatory motion around the rotational axis z' of the arrangement that is approximately parallel to the axis of the terminators. With this rotation and a relative displacement between the arm of the robot and the table 225, it is possible to modify the spacing of the processing tracks generated on the processing surface 81 and to preferably set them smaller than corresponds to the dimension "A" that has been set.

Fig. 42c indicates an example of the robot that can be constructed, for example, of components of Montech-Deutschland GmbH, Postfach 1949, 79509

Lörrach. A horizontal-linear unit 263 is secured on a stand system "Quickset" 262, [said]the unit 263 in turn accepting a vertical-linear unit 264 having a rotatory drive 265. The actual robot arm 260 is seated at the rotatory drive, the profiled rail 256 being secured to [said]the arm 260 with the connection 261. Another horizontal-linear unit is possible but not shown.

The various motion directions of the table 225 can be realized with the same element, whereby the motion directions can also be partly allocated to the table and partly to the profiled rail. The housing for the acceptance of individual components, the cooling system, the control for the lasers, the pump sources for the fiber lasers, [whereof only]and the terminators 26, 94 are shown, the arrangement for removing the material eroded from the processing surface and the machine control for the drives are not shown in the Figures.

Fig. 43 shows a further flatbed arrangement with the inventive laser radiation source. The material to be processed with the processing surface 81 is located on a table 247 that is seated on guides 251 and can be moved in the feed direction u precisely with a spindle 252. The spindle 252 is placed into rotation by a motor 254 via a gearing 253 that is driven proceeding from a control electronics 255. The laser radiation emerging from the laser gun 23 generates the processing points B_1 through B_n in an intermediate image plane 228 (not shown here) that, for example, is shown in Fig. 44. The laser radiation is conducted via deflection mirror 241 and an optics 242 belonging to an optical unit onto a rotating mirror 243 that, for example, can have one mirror face that, however, can also be [fashioned]designed as a rotating mirror having a plurality of mirror faces and that is placed into a rotatory motion by a motor 244 driven proceeding from the control electronics 255. The rotating mirror 243 steers the laser radiation over the processing surface line-by-line in arrow direction v. An optics 245 belonging to the optical device is located between the rotating mirror and the processing surface, the job of [said]the optics 245 being to generate a sharp processing spot on the processing surface over the entire line length, this processing spot being potentially composed of a plurality of processing points B_1' through B_n' that are

shown in Fig. 43. As a result of the rotation of the rotating mirror, the processing points generate processing tracks 224 on the processing surface 81 as shown, for example, in Figs. 35, 36 and 37. Preferably, a long deflection mirror 246 is provided between the processing surface 81 and the optics 245 in order to achieve a compact structure. The laser gun 23 is preferably turned in the prism 248 such that the processing tracks have the desired spacing from one another on the processing surface, this being shown in Fig. 35. The fixing of the laser gun can [ensue]occur with a strap retainer (not shown). An inventive arrangement 249 for removing the material eroded from the processing surface is attached close to the processing surface 81 over the entire line length, [said]the arrangement 249 being capable of being provided with a glass plate 230 over the entire length and being shown in greater detail in Fig. 43b. In Fig. 43, a laser gun with the lenses 102 and 103 according to Fig. 4b and a beam path illustrated in Fig. 20 can be provided; however, all other types of inventive laser guns can also be used. Further, a plurality of laser radiation sources can be attached in such a flat bed arrangement in order to speed the processing procedure up. Inventively, a second laser radiation source with the [appertaining]corresponding optics and the arrangement 249 for removing the material eroded from the processing surface can be attached [such]opposite the illustrated arrangement such that further processing tracks derive on the processing surface.

It lies within the framework of the invention that the rotating mirror can also be replaced by an oscillating mirror. It also lies in the scope of the invention that the rotating mirror can be replaced by two oscillating mirrors, whereby the oscillatory direction of the one mirror, called "mirror u", lies on the processing surface 81 in the direction referenced u, and whereby the oscillating direction of the other mirror called "mirror v", lies on the processing surface 81 in the direction referenced v.

An arrangement having oscillating mirrors is especially well-suited for fast incising of photo-voltaic cells, as was described in detail under Fig. 42. The cell to be incised is placed onto the table 247 with, for example, a loading device that

is not shown in Fig. 43 and is brought into the correct position. The laser gun 23 is turned such that the desired spacings in the processing tracks arise in the two processing directions u and v. In a first processing event, for example, mirror u draws the contact lines, whereas mirror v undertakes the correct positioning of the contact line packets. In a second processing event, mirror v draws the bus bars, whereas mirror u undertakes the correct positioning of the line packets. In these processing events, the photo-voltaic cell is not moved. It lies within the scope of the invention that the table 247 can be replaced by a magazine (not shown) wherein a specific [plurality]number of photo-voltaic cells are delivered for processing, that the processing of the respective cell [ensues]occurs directly in the magazine, and that the processed cell is automatically removed from the magazine after the processing and is transferred into a second magazine, whereby the next, unprocessed cell for processing moves forward to take the place of the removed cell.

As a result of the extremely high beam quality of the laser radiation source that derives due to the fiber laser working refraction-limited, a nearly parallel laser beam bundle can be generated, as shown in Fig. 43 between the optics 242 and rotating mirror 243 and as can also be seen in Fig. 4 between the lenses 57 and 61. Consequently, it is also possible to remove the optics 245, the rotating mirror 243 and the deflection mirror 246 in Fig. 43 and replace them by a deflection mirror (not shown) that deflects the nearly parallel laser beam bundle emerging from the optics 242 in the direction of the processing surface 81 and onto an objective lens (not shown) having a short focal length that is implemented similar to the objective lenses 61, 103 or 112.

[D]The deflection mirror and the objective lens are inventively combined with one another to form a unit and slide back and forth on a guide rail (not shown) in the direction v, so that a [plurality]number of parallel processing tracks corresponding to the [plurality]number of channels in the laser radiation source are registered on the processing surface (81) similar to previously with the rotating mirror 243 and the optics 245.

Inventively, the guide rail is implemented as a bearing having very low friction, for example as an air bearing or as a magnetic bearing. The drive of the unit composed of the objective lens and the deflection mirror in the direction v and back respectively [ensues]occurs with a thrust into the corresponding direction that, for example, is carried out by a preferably contact-free electromagnetic system, whereby the energy acquired from the deceleration of the moving unit is partially re-employed for the drive. Parts of the guide rail, deflection mirror and objective lens are, for example, accommodated in a closed space that contains windows for the entry and the exit of the laser radiation and can be evacuated in order to reduce frictional losses. [D]The drive and guide rail represent a linear drive for the unit composed of the objective lens and the deflection mirror.

It lies within the framework of the invention that the respective, true position of the moving unit can be determined for correction purposes via, for example, an optical reference track. An arrangement 249 serves for the removal of the material eroded from the processing surface [(]81[)]. The advantage of such an arrangement is that it can be very cost-beneficially realized for long path lengths and high resolutions, and that it can be set to various formats by displacement of the one and/or other drive. A plurality of such units can also be arranged in parallel in order to increase the processing speed.

Fig. 43a shows a simplification of the arrangement according to Fig. 43 in that the two lenses 102 and 103 have been removed from the laser gun. Given a corresponding spacing of the laser gun from the deflection mirror 241, the divergent laser ray bundles emerging from the lens 101 are focused onto the processing surface 81 with the lenses 241 and 245 and generate the processing points B_1 through B_n that are identical to the processing points B_1' through B_n' in this case.

Fig. 43b shows the arrangement 249 for removing the material eroded from the processing surface in greater detail. The functioning has been described in detail in Fig. 34.

Fig. 44 shows a hollow bed arrangement for processing material with the inventive laser radiation source. Hohlbett arrangements are known; for example, two arrangements having hollow bed are described in the publication "Der Laser in der Druckindustrie" by Werner Hülsbuch[[sic]], Verlag W. Hülsbusch, Constanc, pages 461 and 562. The material to be processed with the processing surface 81 is located in a cylinder or, preferably, a part of a cylinder 236 having the radius R. This arrangement is referred to as a hollow bed on whose axis a bearing 229 with a rotating mirror 233 is arranged. The rotating mirror can, for example, have one mirror face but can also be [fashioned]designed with a plurality of mirror faces and can be placed into rotation by a motor 234 and be arranged on a carriage (not shown) displaceable in the direction of the cylinder axis relative to the cylinder 236. An optics 231 belonging to an optical device and a mirror 232 are arranged as well on the carriage (not shown) in the proximity of the processing surface 81. Further, a deflection mirror 227 and the laser gun 23 as well as an arrangement 235 - close to the processing surface 81 - for removing the material eroded from the processing surface, which is described in greater detail in Fig. 34, are located on the carriage. The ray bundles 226 emerging from the laser gun generate processing points B_1 through B_n in an intermediate image plane 228 that are transmitted onto the processing surface 81 with the deflection mirror 227, the mirror optics 231, 232 and the rotating mirror 233. Here, they generate the processing points B_1' through B_n'. The processing points B_1' through B_n' that form the processing spot generate processing tracks 224 (Figs. 35, 36 and 37) across the entire line length that are registered sharply focused over the entire line length as a result of the constant radius of the hollow bed. The advantage of the illustrated arrangement is [comprised therein]that a compact structure can be achieved. In particular, the illustrated arrangement enables a small angle δ between the axis of the ray bundle incident onto the rotating mirror 233 and the ray bundle that is reflected by the rotating mirror onto the processing surface, which is desirable for low distortion in the recording geometry on the processing surface. The laser gun is preferably seated in a prism (not shown) and is secured

with a fastening strap (likewise not shown). The laser gun can be turned around its axis and can be displaced in the axial direction. As a result of the rotation, the distance between the processing tracks can be modified, this being shown in Fig. 35. The spacing from the processing surface can be modified by the displacement. An inventive arrangement 235 for removing the material eroded from the processing surface is attached over the entire line length close to the processing surface 81, [said]the arrangement 235 being capable of being [fashioned]designed similar to what is shown in Fig. 43b, whereby it is implemented in curved fashion corresponding to the radius R of the cylinder 236 and can be provided with a curved glass plate 237 (not shown) over the entire length, the functioning thereof having been described in detail under Fig. 34. In Fig.44, a laser gun having the lenses 102 and 103 according to Fig. 4b and a beam path shown in Fig. 20 are provided. However, all other types of the inventive laser gun can be utilized. Further, a plurality of laser radiation sources can also be attached in such a hollow bed arrangement in order to speed the processing event up. For example, a second rotating mirror and a second laser radiation source as well as a second arrangement 235 for removing the material eroded from the processing surface can be attached [such]opposite the illustrated arrangement such that further processing tracks derive on the processing surface.

Fig. 44a shows a simplification of the arrangement according to Fig. 44, in that the two lenses 102 and 103 were removed from the laser gun. Given a corresponding spacing of the laser gun from the deflection mirror 227, the divergent laser ray beams emerging from the lens 101 are focused onto the processing surface 81 with the lens 231 and generate the processing points B_1 through B_n that are identical to the processing points B_1' through B_n' in this case.

While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only the preferred embodiment has been shown and described and that all changes and modifications that come within the spirit of the invention are desired to be protected.

Abstract

[The invention is directed to]In a laser radiation source, preferably for[ ] processing material, as well as to an arrangement for processing material with[ ] the laser radiation source and to the operation thereof[. F], for achieving a high[ ] power density and energy, the laser radiation source[(1)] comprises a plurality of directly modulatable diode-pumped fiber lasers [(2)]whose outputs are arranged [ ]in a bundle. The laser radiation emerging from the outputs of the fiber lasers [(2)]is merged and bundled [such]with an optical unit such that the laser radiation is incident onto a processing surface [(81) in]at a processing spot [(24)].
[Figure 1]

SPECIFICATION

TITLE

LASER RADIATION SOURCE

BACKGROUND OF THE INVENTION

The invention is directed to a laser radiation source, preferably for processing materials, as well as to an arrangement for processing material comprising a laser radiation source and to the operation thereof.

When processing materials with focused energy beams such as, for example, electron beams or laser beams, there are applications wherein structures must be produced that make high demands of the focused energy beam with respect of its beam geometry and the focusability of the beam. At the same time, however, a high beam power is required.

A typical case wherein extremely fine structures must be produced on a processing surface is the production of printing forms, whether for rotogravure, offset printing, letter press printing, silk screening or flexo-printing or for other printing processes. In the production of printing forms, it is necessary to produce extremely fine structures on the surface of the printing forms, since highly resolved image information such as text, screened images, graphics and line work must be reproduced with the surface of the printing forms.

In rotogravure, the printing forms were produced in the past with etching, which had led to good results; the etching, however, was replaced over the course of time by more environmentally friendly engraving with electromagnetically driven diamond stylii. Printing cylinders whose surface is composed of copper are normally employed as printing forms in rotogravure, these fine structures required for the printing being engraved thereinto in the form of cups with the diamond stylus. The printing cylinders are introduced into a printing press after they are produced, the cups being filled with ink therein. Subsequently, the excess ink is removed with a doctor blade and the remaining ink is transferred

onto the printed matter during the printing process. Copper cylinders are thereby employed because of their long service life in the printing process. A long service life is required given large editions, for example, in particular, in magazine printing or packaging printing, since the surface of the printing form wears in the printing process as a result of the influence of the doctor blade and of the printed matter. In order to extend the service life even further, the printing cylinders are provided with a copper layer that has been galvanized on; on the other hand, solid cylinders of copper are employed. Another possibility of making the service life even longer is comprised in galvanically chrome plating the copper surface after the engraving. In order to achieve an even longer service life, what is referred to as "hot chrome plating" is additionally applied, whereby the galvanic process is carried out under elevated temperature. The longest service lives that could previously be obtained were achieved therewith. Deriving therefrom is that copper is the most suitable as the material for the surface of rotogravure cylinders. Materials other than copper have not hitherto proven themselves for large editions.

When producing the cups, the drive of the diamond stylus occurs via an electromechanically driven magnet system having an oscillating armature to which the diamond stylus is secured. Such an electromechanical oscillatory system cannot be made arbitrarily fast because of the forces that must be exerted in order to engrave the cups. This magnet system is therefore operated above its resonant frequency so that the highest engraving frequency, i.e. the highest engraving speed can be achieved. In order to increase the engraving speed even further, a number of such engraving systems have been arranged side-by-side in the axial direction of the copper cylinder in given current engraving machines. This, however, still does not suffice for the short engraving time of the printing cylinders required currently, since the engraving time directly influences the actuality of the printing result. For this reason, rotogravure is not employed for newspaper printing but mainly for magazine printing.

Upon utilization of a plurality of engraving systems, a plurality of what are referred to as lanes are simultaneously engraved into the surface of the printing cylinder. For example, such a lane contains one or more entire magazine pages. One problem that thereby arises is that cups having different volumes are generated in the individual lanes given the same tone value to be engraved, this occurring because of the different engraving systems that are driven independently of one another and leading to differences in the individual lanes that the eye detects during later observation. For this reason, for example in packaging printing, only one engraving system is employed so that these errors, which are tolerated in magazine printing, do not occur.

When engraving the cups, the cup volume is varied dependent on the image content of the master to be printed. The respective tone value of the master should thereby be reproduced as exactly as possible during printing. When scanning the masters, the analog-to-digital converters having, for example, a resolution of 12 bits are utilized for recognizing the tone value gradations for reasons of image signal processing (for example, gradation settings), this corresponding to a resolution of 4096 tone values in this case. The signal for the drive of the electromagnetic engraving system is acquired from this high-resolution image information, said signal usually being an 8-bit signal corresponding to a resolution into 256 tone value gradations. In order to generate the corresponding volumes that are required for achieving this scope of gradations, the penetration depth of the diamond stylus into the copper surface is varied with the drive of the magnet system, whereby the geometry of the cups changes between approximately 120 μm diameter given a depth of 40 μm and approximately 30 μm diameter given a depth of 3 μm. Because only an extremely small range of variation in the depth of the cups between 40 μm and 3μm is available, the penetration depth of the stylus with which the cups are engraved must be exactly driven to fractions of a μm in order to reproducibly achieve the desired range of gradation. As can be seen therefrom, an extremely high precision is required in the engraving of the cups, at least as regard to the generation of the

required diameters and depths of the cups. Since the geometry of the engraved cups is directly dependent on the shape of the stylus, extremely high demands are also made of the geometry of the diamond stylus which, as has been shown, can only be achieved with extremely high expense and with a high rejection rate in the manufacture of the stylii. Moreover, the diamond stylus is subject to wear since, when engraving a large printing cylinder having fourteen lanes, a circumference of 1.8m and a length of 3.6m given a screen of 70 lines/cm - which corresponds to a plurality of 4900 cups/cm^2, a stylus must engrave approximately 20 million cups. When one of the diamond stylii breaks off during the engraving of a printing cylinder, then the entire printing cylinder is unuseable. On the one hand, this causes a considerable financial loss and, on the other hand, represents a serious loss of time since a new cylinder must be engraved, postponing the start of printing by hours. For this reason, users frequently replace stylii earlier than necessary. As can also be seen therefrom, the endurance of the diamond stylii is also a critical concern.

All in all, electromagnetic engraving is well-suited for producing high-quality rotogravure cylinders; however, it has a number of weak points and is extremely complicated and one would like to eliminate these disadvantages with a different method.

The cups produced in this way, which are intended to accept the ink later, are also arranged on the surface of the printing form in conformity with a fine, regular screen, namely the printing screen, whereby a separate printing cylinder is produced for each ink, and whereby a different screen having a different angle and different screen width is respectively employed. When printing in the printing press, given these screens, narrow bridges remain between the individual cups, these supporting the doctor blade that removes the excess ink after the inking. Another disadvantage of this operating mode of this electromechanical engraving is that texts and lines must also be reproduced in screened fashion, which leads to step-patterns in the contours of the written characters and the lines that the eye perceives as being disturbing. This is one disadvantage compared to the

widespread offset printing wherein this stepping can be kept an order of magnitude lower, which can then no longer be perceived by the eye, and which leads to a better quality that rotogravure could hitherto not achieve. This is a serious disadvantage of the rotogravure process.

In rotogravure, no stochastic screens can be generated wherein the size of the cups and the position of the cups can be randomly distributed corresponding to the tone value; this is not possible when engraving with the diamond stylus. Such stochastic screens are also frequently referred to as "frequency-modulated screens" that have the advantage that details can be reproduced far better with no Moirè, this also leading to a better image quality than in rotogravure.

It is also known to utilize the electron beam engraving method applied in the processing of materials for generating the cups, this having exhibited extremely good results because of the high energy of the electron beam and the incredible precision with respect to the beam deflection and beam geometry.

This method is described in the publication, "Schnelles Elektronenstrahlgravierverfahren zur Gravur von Metallzylindern", Optik 77, No. 2 (1987) pages 83-92, Wissenschaftliche Verlagsgesellschaft mbH Stuttgart. Due to the extremely high expense that is required for the hardware and electronics, electron beam engraving has hitherto not prevailed in practice for the engraving of copper cylinders for rotogravure but only in the steel industry for surface engraving of what are referred to as textured drums for sheet metal manufacture wherein textures are rolled into the sheets.

It has been repeatedly proposed in the trade literature as well as in the patent literature to engrave copper cylinders with lasers. Since copper, however, is an extremely good reflector for laser radiation, extremely high powers and, in particular, extremely high power densities of the lasers to be employed are required in order to penetrate into the copper and melt it. There has hitherto not been any laser engraving unit with laser radiation sources having a correspondingly high power density and energy with which one succeeds in

providing the copper cylinders for rotogravure with the required cup structure in the copper surface.

Attempts have nonetheless been made to utilize lasers for rotogravure in that a switch has been made to materials other than copper. Thus, for example, the publication DE-A-19 20 323 has proposed to prepare copper cylinders with chemical etching such that the surface of the copper cylinder already comprises cups that have a volume that corresponds to the maximum printing density. These cups are filled with a solid filler material, for example plastic. Much of the filler material is then removed with a laser until the desired cup volume has been achieved. This method in fact manages with a lower laser power than would be necessary in order to melt and evaporate the copper as in electron beam engraving. In this method, however, the remaining plastic is attacked by the solvent of the ink in the printing process and is decomposed, so that only a low print run is possible. This method has not proven itself in practice and has thus not been utilized.

The publication of the VDD Seminar Series, "Direktes Lasergravierverfahren für metallbeschichtete Tiefdruckzylinder", published within the framework of a "Kolloquium vom Verein Deutscher Druckingenieure e.V. und dem Fachgebiet Druckmaschinen und Druckverfahren, Fachbereich Maschinenbau, Technische Hochschule Darmstadt", by Dr. phil. Nat. Jakob Frauchiger, MDC Max Dätwyler, AG, Darmstadt, 12 December 1996, has proposed that rotogravure cylinders plated with zinc be engraved by a quality-switched Nd:YAG high-power solid-state laser pumped with arc lamps. In this method, the volume of the cups is defined by the optical power of the laser. The laser power required for the engraving is transmitted onto the cylinder surface via an optical fiber whose output is imaged onto the cylinder surface through a variable focusing optics. One disadvantage of this method is that the arc lamps required for pumping the laser have a relatively short service life and must be replaced after approximately 500 hours of operation. The engraving cylinder becomes unuseable given a failure of the pump light source during the engraving.

This corresponds to a failure of the diamond stylus in electromechanical engraving and results in the same disadvantages. A preventative replacement of the arc lamps is cost-intensive and work-intensive, particularly since one must count on the fact that the laser beam must be re-adjusted in position after the replacement of the lamps. These lamp-pumped solid-state lasers also have a very poor efficiency since the laser-active material absorbs only a slight fraction of the available energy from the pump source, i.e. from the arc lamp here, and converts into laser light. Particularly given high laser powers, this means a high electrical connection cost, high operating costs for electrical energy and cooling and, in particular, a considerable expense for structural measures due to the size of the laser and the cooling unit. The space requirements are so high that the laser unit must be located outside the machine for space reasons, this in turn being accompanied by problems in bringing the laser output onto the surface of the printing cylinder.

A critical disadvantage of this method is that zinc is significantly softer than copper and is not suitable as a surface material for printing cylinders. Since the doctor blade with which the excess ink is removed before printing in the printing press is a steel blade, the zinc surface is damaged after a certain time and the printing cylinder becomes unuseable. A printing cylinder having a surface of zinc therefore does not even begin to approach as long a service life in printing as a printing cylinder having a surface of copper. Printing forms having a zinc surface are therefore not suitable for high press runs.

Even if the zinc surface is chrome-plated after the engraving, as has been also proposed in order to lengthen the service life, the durability does not come close to that of normal copper cylinders. Chrome does not adhere to zinc as well as it adheres to copper and what is referred to as "hot chrome plating", which is successfully employed given copper cylinders in order to achieve an optimum adhesion of the chromium on the copper, is not possible given zinc since the zinc would thereby melt. Since the chrome layer does not adhere very well on the zinc, it is likewise attacked by the doctor blade, which leads to a relatively early

failure of the printing cylinders. When, in contrast thereto, copper cylinders are chrome-plated according to this method, then incredibly high press runs are possible since the chromium firmly adheres on the copper surface, so that these copper cylinders out perform the chrome-plate zinc cylinders by far.

It proceeds from the publication EP-B-0 473 973, which is likewise directed to the method described above, that an energy of 6 mWsec is required in this method given zinc for cutting a cup having a diameter of 120 μm and a depth of 30 μm. An energy of 165 mWsec is recited in this publication for copper, this amounting to a factor of 27.5 for the required laser power. Lasers having a continuous-wave performance of several kilowatts given good beam quality are thus required in order to produce cups in copper with a speed that is accessible for the printing industry. Such a power, however, cannot be produced with the laser arrangement described above. For this reason, it is likewise only possible to engrave a zinc surface.

Such a laser arrangement, which is composed of a single solid-state laser, in fact makes it possible to process rotogravure cylinders having a zinc surface; if, however, one wishes to utilize the advantages of the copper surface and stay with copper cylinders and engrave these with a laser, the high power density required for penetration into the surface of the copper and the high energy required for melting the copper must be inevitably exerted. This, however, has not hitherto been successfully done with a solid-state laser.

It is known that the beam quality in solid-state lasers, i.e. the focusability, decreases with increasing power. Even if the power of the solid-state lasers were to be driven up or if a plurality of solid-state lasers were directed onto the same cup or parts thereof, it would therefore not be possible to satisfactorily engrave copper cylinders for rotogravure with such a laser because the precision of the laser beam, as offered by the electron beam, required for generating the fine structures cannot be achieved. If the laser power were increased given this apparatus, then a further problem would arise: the focusing of high radiant intensity into optical fibers is, as known, difficult. The fibers burn at high power

as a consequence of misadjustment at the infeed location. If one wishes to avoid this, however, the fiber diameter would have to be enlarged which, however, in turn has the disadvantage that the fiber diameter would have to be imaged onto the processing material with even greater demagnification. A demagnified imaging, however, leads to an increase in the numerical aperture on the processing surface and, consequently, to a reduced depth of field on the processing surface. As proposed, the distance from the processing surface could be kept constant. When, however, the beam penetrates into the surface of the material, then a defocussing automatically derives. This has a disadvantageous influence on the required power density and on the exact dot size. Since, however, the diameter of the processing spot and the energy of the beam determine the size of the cup, it then becomes difficult to make the cup size as exactly as required by the desired tone value. For this purpose, it would also be necessary that the laser power is exactly constant and also remains constant over the entire time that is required for a cylinder engraving. When this is not the case, the cup size changes and the cylinder becomes unuseable. This cannot be compensated by varying the size of the processing spot since it is not possible to adequately vary the processing spot in shape.

Further, a complicated modulator is required given such an arrangement. As known, modulators for extremely high laser powers are slow, this leading to a reduction of the modulation frequency and, thus, of the engraving frequency. When, however, the engraving frequency is too low, the energy diffuses into the environment of the processing spot on the processing surface without cutting out a cup. It is therefore necessary to also exert a high power in addition to the high energy for the cutting.

The publication "Der Laser in der Druckindustrie", by Werner Hülsbusch, page 540, Verlag W. Hülsbusch, Konstanz, describes that it is particularly a matter of a high power density in processing materials. Given power densities of typically above 10^7 through 10^8 W/cm^2, a spontaneous evaporation of the material occurs in all materials, this being accompanied by a sudden absorption rise, which

is especially advantageous since the laser power is then no longer reflected from the metal surface. When, for example, a laser source of 100 W is available, then the processing spot diameter may not be larger than 10 μm in order to arrive at these values in the region, as proceeds from the following equation: 100 W : (0.001 cm x 0.001 cm)=10^8 W/cm^2.

SUMMARY OF THE INVENTION

One object of the present invention is to improve a laser radiation source, preferably for processing materials, as well as an arrangement for processing materials having a laser radiation source and the operation thereof such that an extremely high power density and energy are achieved in a cost-beneficial way, and such that both the beam shape with respect to flexibility, precision and beam positioning as well as the beam power can be exactly controlled even given significantly higher laser powers.

According to the present invention, a laser radiation source is provided for generating laser beams with high power density and higher energy for processing material. A plurality of diode-pumped fiber lasers are provided having outputs arranged in a first ordering pattern. An optical unit is provided connected to the outputs of the fiber lasers wherein laser beams emerging from the outputs of the individual fiber lasers are shaped and aligned such that they impinge onto a processing surface in a second ordering pattern.

Further advantageous developments and improvements with respect to the apparatus for processing materials with the laser beam source and the operation thereof are discussed hereafter.

This laser radiation source comprises a plurality of diode-pumped fiber lasers whose output radiation beams impinge the processing location next to one another and/or over one another or in a point or bundle and thus enables the generation of a processing spot that is designationally variable in shape and size, even given extremely high laser powers and extremely high power densities. According to the invention, these fiber lasers can be implemented as continuous wave lasers or as quality-switched lasers, also referred to as Q-switch lasers,

whereby they are advantageously internally or externally modulated and/or comprise an additional modulator. Q-switch lasers have an optical modulator available to them within the laser resonator, for example an acousto-optical modulator, that, in its opened condition, interrupts the laser effect given a pump radiation that continues to exist. As a result thereof, energy is stored within the laser resonator, this being output as a short laser pulse having high power when the modulator is closed in response to a control signal. Q-switch lasers have the advantage that they emit short pulses having high power, which briefly leads to a high power density. An advantageous elimination of the molten and evaporated material is enabled in the pulsed mode due to the brief-term interruptions in the processing event. Instead of switching the quality, a pulsed mode can also be generated with internal or external modulation.

The processing spot can be designationally modified in shape and size in that different numbers of lasers are provided that can be switched on for shaping the processing spot. It is thereby especially advantageous that the depth of the cut cup can be determined by the laser energy independently of its shape and size. Further, a control of the energy of the individual lasers can also generate any arbitrary beam profile within the processing spot and, thus, any arbitrary profile within the cup as well.

Further advantages of the present invention compared to known laser radiation sources are comprised therein that the infeed of the radiant power from a solid-state laser into an optical fiber can be eliminated but the exit of the fiber laser supplies diffraction-limited radiation that, according to the invention, can be focused onto less than a 10 μm diameter, as a result whereof an extremely high power density is achieved given the greatest possible depth of field.

Given a traditional arrangement with solid-state lasers, the size of the processing spot lies in the region of approximately 100 μm. Given the present invention, thus a power density that is improved by the factor 100 derives, and a design possibility in the area of the processing spot that is improved by the factor 100 derives.

Due to the high precision and due to the shape of the processing spot that can be designed in very fine fashion, extremely fine screens, also including the stochastic screens that are also called frequency-modulated screens (FM screens) and, thus extremely smooth edges in lines and written characters can be economically produced, so that rotogravure no longer need be inferior to offset printing in terms of printing quality.

Due to the operating mode of the laser radiation source of the invention, it is also possible to link arbitrary raster widths to arbitrary screen angles and apply arbitrary different screen widths and arbitrary different screen angles at arbitrary locations on the same printing cylinder. Line patterns and text can also be applied independently of the printing screen as long as one sees to sufficient supporting locations for the doctor blade.

One advantage of the invention is that the differences in the data editing for the production of the printing form are reduced to a minimum between rotogravure and offset printing, this yielding substantial cost and time savings. Up to now, the data for the rotogravure are acquired by conversion from the data already present for the offset printing because a signal is required for the drive of the engraving system that defines the volume of a cup, whereby the area of a screen dot is determined in offset printing. As a result of the multiple arrangement of lasers, the laser beam source of the invention makes it possible to vary the area of a cup given constant depth, for which reason it is no longer required to convert the data for offset printing into data for the rotogravure. The data for the offset printing can be directly employed for engraving the rotogravure forms.

Another advantage of the invention is that both the area of a cup as well as the depth can be controlled independently of one another with this laser radiation source, this leading to that a greater number of tone value gradations that can be reproducibly generated, this leading to a more stable manufacturing process for the printing cylinders and to an improved printing result.

It is also an essential advantage that the energy can be unproblemmatically transported from the pump source to the processing point with the fiber, namely the fiber laser itself, or with a fiber that is welded on or, respectively, attached in some other way, this yielding an especially simple and space-saving structure.

Another advantage of the invention is that the efficiency of such an arrangement with fiber lasers is significantly higher than the efficiency of solid-state lasers, since absorption efficiencies of more than 60% are achieved for fiber lasers, these lying only at approximately half given traditional diode-pumped solid-state lasers and being even far lower given lamp-pumped solid-state lasers. Given the required power of several kilowatts for an efficient engraving of rotogravure cylinders, the efficiency of the lasers is of incredible significance for the system costs and the operating costs.

Further, a multiple arrangement of lasers yields the advantage that the outage of a laser is less critical than given a single-channel arrangement. When the only laser that is present given the single-channel arrangement fails during the engraving of a printing cylinder, the entire printing cylinder is unuseable. When, however, a laser fails given a multiple arrangement, then the power of the remaining lasers can, for example, be slightly boosted in order to compensate the failure. After the end of the engraving, the laser that has failed can then be replaced.

The dissertation, "Leistungsskalierung von Faserlasern", Physics Department of the University of Hannover, Dipl.-Phys. Holger Zellmer 20 June 1996, fiber lasers are discussed as being known. These lasers, however, had already been proposed in 1963 by Snitzer and Köster, without these having been previously utilized for processing materials given high powers. Although powers of up to 100 W can be fundamentally achieved with the lasers described in this dissertation, no useable arrangements are known for utilizing these lasers for purposes of the present invention.

The publication WO-A-95/16294 has already disclosed phase-coupled fiber lasers; however, these are extremely involved in terms of manufacture and

are not suitable for industrial employment. It had hitherto not been recognized to bring lasers of this simple type to high power density and energy in the proposed, simple way and to utilize them for erosive processing of materials.

For example, the resonator length of the individual lasers must be kept exactly constant to the fraction of a micrometer, for which purpose what are referred to as "piezoelectric fiber stretchers" are utilized. As a result of the complex structure, it is likewise not possible to construct the laser unit modularly, i.e. of components that are simple to assemble and to be multiply employed or to replace individual laser components as needed on site as a consequence of the great number of optical components within a phase-coupled laser. Moreover, the optical losses are extremely high, and the pump radiation absorption of the laser-active medium is low, which results in a low efficiency of the arrangement. Although fiber lasers are not particularly susceptible to back-reflections in and of themselves, phase-coupled lasers exhibit a great sensitivity to back-reflections due to their very principle, i.e. when portions of the emitted radiation proceed back into the laser resonator due to reflection or dispersion, as is unavoidable when processing materials. These back-reflections lead to uncontrolled output amplitudes and cause the laser to shut down. Although what are referred to as optical isolators are known, these being intended to attenuate such back-reflections, these involve a number of disadvantages in practice, which, for example, include the optical losses, the high price and the inadequate attenuation properties. The lasers for the purpose of the invention of processing materials need not only exhibit a high power density but also must be able to supply the required energy for cutting out the cups, must be extremely stable in terms of the emitted radiation and must have a very good efficiency.

Further, US-A-5,694,408 has disclosed a laser system wherein a master oscillator generates low-power radiation energy at a specific wavelength, this being optically intensified and it being distributed for further post-amplification onto a plurality of post-amplifiers, in order to then be in turn united to form a common beam, a precise phase readjustment of the individual post-amplified

signals being required for this purpose in order to avoid interferences in the output signal. This requires complicated measuring and control procedures and involved actuating elements, for which purpose, for example, electro-optical phase modulators must be utilized, these being extremely expensive and having to be operated with extremely high voltages.

Further, US-A-5,084,882 discloses a phase-coupled laser system that employs a plurality of fibers or fiber cores in a bundle, the core thereof being, on the one hand, large compared to its cladding or its spacing in order to achieve the phase coupling; on the other hand, this should only have a diameter of a few micrometers since it is a matter of single-mode fibers. This system is mainly provided as an optical intensifier.

Another phase-coupled laser system that is likewise implemented in an extremely complex way and that is composed of a plurality of what are referred to as "sub-oscillators" is disclosed by GB-A-21 54 364 under the title "Laser Assemblies", having already been disclosed in 1984; however, no industrial realizations with such phase-coupled laser systems have become known up to now.

It has also not been previously proposed to combine a number of the initially cited fiber lasers in a simple way, i.e. without a complex phase coupling or the like, to form a compact, rugged and service-friendly radiation source for processing materials and, for example, to employ this for multi-track recording. An inventive, multiple arrangement of such simple lasers that can be cost-beneficially manufactured in quantity in several tracks and levels yields enormous advantages for the purposes of the invention that would certainly not have escaped attention if the invention solution had been known.

A further advantage of fiber lasers is their clearly lower tendency to oscillate when energy proceeds back into the laser. Compared to traditional solid-state lasers, fiber lasers have a resonance overshooting that is lower by an order of magnitude in terms of its transfer function, this having been very positively proven during operation. When processing materials, namely, one cannot always

prevent energy from being reflected from the processing location back into the laser because the melting material is explosively hurled in unpredictable directions and thereby flies through the laser beam before it can be removed and neutralized by particular techniques that are presented in one embodiment of the invention.

An essential advantage of the multiple arrangement of fiber lasers without phase coupling is that the individual lasers behave differently in case of a back-reflection. This is related to the fact that, for example, some of the lasers are not affected at all by a back-reflection and others may possibly be effected only with a delay. The probability is therefore high that oscillations of the individual lasers, if they occur at all, are superimposed such that they have no negative influence on the quality of the results of the engraving.

The laser radiation source of the invention can also be advantageously utilized for all other types of processing materials or transferring materials wherein high power density, high energy and great precision or, too, high optical resolution are important. In addition to engraving rotogravure cylinders having a copper surface, other materials such as, for example, all metals, ceramics, glass, semiconductor materials, rubber or plastics can be processed and/or materials can be stripped from more specifically prepared carrier materials and transferred onto other materials at high speed and with high precision. In addition to those that are uncoated, moreover, rotogravure cylinders, printing plates or printing cylinders that are coated with masks as well as all types of printing forms can also be produced or, respectively, processed at high speed and with high resolution for offset printing, letter press printing, silk screening, flexo-printing and all other printing processes. For example, the offset printing plates having metal coating (bi-metal plates) that are employed for printing extremely large print runs in offset printing and similar materials can be provided with images in an environmentally friendly way, this having been hitherto possible only with etching.

Further, materials can be processed that contain a magnetizable surface, in that the parts of the material magnetized in large-area fashion by a pre-

magnetization process are de-magnetized by briefly heating selected processing points to temperatures that lie above the Curie point, when heated with the inventive laser radiation source. The material provided with images in this way for applications in printing technology can serve as a print master in conjunction with a corresponding toner.

As a result of the high power density of the inventive laser radiation source, it is also possible to directly process chromium. Thus, for example, printing cylinders of copper can already be chrome-plated for rotogravure before the laser engraving, this eliminating a work step after the engraving and benefitting the timeliness. Since the printout behavior of a cup engraved in copper is also better than that of a chrome-plated cup and its volume is more precise, this method also yields even better printing results in addition to the high service life as a result of the remaining chromium layer and the improved timeliness.

The employment of the inventive laser radiation source, however, is not limited to employments in printing technology but can be utilized anywhere that it is important to erode material or change the properties of the material by energy irradiation with lasers given high resolution and high speed. Thus, for example, the aforementioned texture drums can also be produced with the inventive laser radiation source. Further, the patterns of interconnects for printed circuit boards, including the boards for the components, preferably for multi-layer printed circuit boards, can be produced by eroding the copper laminate and allowing the interconnects to stand, and by eroding copper laminate and carriers at the locations of the bores. Further, the surface structure of material surfaces can be partially modified by partial heating. For example, extremely fine structures in the hardness of material surfaces can be produced in large-area fashion in this way, this being particularly advantageous for bearing surfaces since the bearing properties can be intentionally influenced in this way. Further, there are non-conductive ceramic materials at whose surface metal crystallizes out due to energy irradiation, this being capable of being utilized in conjunction with the inventive

laser radiation source for applications that require a high resolution, for example for producing interconnects.

The laser beams can thereby be guided to the processing spot and can be moved across the material in the greatest variety of ways for example, the material to be processed can be located on a rotating drum past which the radiation source is conducted in relative fashion. However, the material can also be located in a plane over which the laser radiation source or its output radiation is conducted past in relative fashion. In a flat bed arrangement as presented in the aforementioned publication "Der Laser in der Druckindustrie" von W. Hülsbusch, Figure 7-28 on page 431 and as likewise disclosed in the publication EP-A-0 041 241, the radiation source presented therein as argon or He Ne laser or, respectively, as laser light source (4) in Figure 3 of the publication can be replaced by the inventive laser radiation source in order to utilize the advantages of the inventive laser radiation source. Further, the material to be processed can be located within a hollow cylinder over which the laser radiation source or its output radiation sweeps in a relative motion.

Inventively, the output of the laser radiation source can also be implemented with a variable number of tracks whose mutual spacings are variable, preferably similar to a long comb, this moving relative to the material to be provided with images. Such an arrangement is disclosed by US-A-5,430,816. It is disclosed therein to direct the radiation of an excimer laser having a strength of approximately 50 watts onto a bundle of what are referred to as stepped index fibers having diameters of 50 through 800 micrometers and to respectively couple a part of the radiation into the individual fibers. The exit of each fiber is then imaged onto the workpiece via a respective positive lens having a diameter of 60 mm, whereby the spacing between the individual processing points must amount to at least 60 mm and a protective mechanism to prevent contamination is required per positive lens. What is disadvantageous is that only a fraction of the laser energy thus proceeds into the respective fibers. The energy distribution turns out very differently and changes in the exit power derive given movement of the

fibers, for which reason what are referred to as scramblers must be utilized in order to avoid this. These scramblers, however, disadvantageously influence the efficiency of the system and increase the costs. Only relatively imprecise bores having a diameter of approximately 130 micrometers can be produced in plastic with such an arrangement. The pulse rate of the laser is the same for all simultaneously produced bores, so that all bores must be implemented of the same size. Moreover, the system is relatively slow since a boring processing lies between one and two seconds. An arrangement having fiber lasers yields tremendous advantages compared thereto: the speed can be increased by several orders of magnitude and metals can also be processed; the precision is substantially greater since fiber lasers also exhibit a stable output power given movement of the laser fibers; and bores having diameters below 10 micrometers can also be unproblemmatically produced. Since each fiber laser can be separately modulated, different processing patterns are possible. Further, the end sections of the fiber lasers can be unproblemmatically implemented smaller than 2.5 mm in diameter, this enabling a clearly smaller spacing between the processing tracks. As a result thereof, it is also possible to employ a shared protective mechanism to prevent contamination of the optics.

Another example for the application of the inventive laser beam source wherein the material is preferably arranged in a plane derives in the semiconductor industry in the processing of what are referred to as wafers, i.e. usually circular disks of suitable semiconductor material that, for example, are incised or cut or can be provided with all conceivable patterns in the surface, of a type that could previously be manufactured only by time-consuming chemical etching processes that were also not environmentally friendly.

For the multi-channel cutting and in sizing of materials, a simplified embodiment of the laser radiation source is inventively possible, as disclosed in the German Patent Application P 198 40 936.2 of the assignee, “Anordnung zum mehrkanaligen Schneiden und Ritzen von Materialien mittels Laserstrahlen”.

A further inventive application of the laser radiation source is established in the manufacture of monitors and displays. For example, the apertured masks for color picture screens as well as the masks of what are referred to as flat picture screens or LCD displays can be manufactured in a more environmentally friendly way with laser processing than with the chemical etching processes that were previously employed, in that the inventive laser radiation source is applied.

A considerable advantage of the inventive laser radiation source is that it has a small volume and has a flexible connection, namely the laser fibers or fibers connected thereto between the pump source and the exit of the radiation at the processing location and thus allows all conceivable operating positions of the laser radiation source or of its beam exit. There are therefore also no limitations for the spatial arrangement of the processing surface, since they can be arranged in an arbitrary attitude in space.

Another advantage of the invention is comprised therein that the radiation beam of the individual lasers with defined values in beam diameter, beam divergence centering and angular direction can be exactly and durably acquired in a terminating section (terminator), as a result whereof a fabrication-suited and service-suited arrangement for forwarding the laser radiation onto the processing surface can be created. Inventively, the radiation beams can thereby be coupled into the fiber dependent on the application, for example as pump spot and/or can be coupled out as parallel laser beam, can diverge at the exit location or, for example, can be focused in a certain distance from the exit point. There is thus a desire to fashion the terminator as small as possible and to provide it with one or more fits as a reference surface or reference surfaces for the alignment of the laser beam.

According to the invention, this is achieved in that the optical fibers are set in the terminator and the position of the optical fibers and/or the position of the emerging radiation beam is exactly adjusted. On the basis of the exact adjustment and of an inventive, correspondingly spatially small embodiment of the terminators which can also be attached to one another in an especially simple way

as a result of a special shaping, it becomes possible to combine the radiation beams of a plurality of fiber lasers and focus them such that the respectively encountered object is achieved and, at the same time, an economical manufacture as well as a cost-beneficial maintenance of the laser radiation source is enabled.

The invention is explained in greater detail below on the basis of Figures 1 through 44a.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic illustration of the laser radiation source;

Fig. 2 is a fundamental illustration of the fiber laser (prior art);

Fig. 2a is an attenuated illustration of the fiber of the fiber laser (prior art);

Fig. 3 is a cross-section through an arrangement for processing material with a laser radiation source of the invention;

Fig. 4 is an illustration of a laser gun for the inventive laser radiation source having a multiple arrangement of fiber lasers;

Fig. 4a is a perspective illustration relating to Fig. 4;

Fig. 4b is a version of Fig. 4;

Fig. 4c is a further version of Figs. 4 and 4b;

Fig. 5 is an example of a terminator for the outfeed of the radiation from a fiber or, respectively, from the fiber of a fiber laser;

Fig. 5a is an example of a multiple arrangement for a plurality of terminators;

Fig. 5b is an example of a terminator having adjustment screws;

Fig. 5c is a cross-section through the terminator according to Fig. 5b in the region of the adjustment screws;

Fig. 6 is an example of a terminator having spherical adjustment elements;

Fig. 6a is a cross-section through the terminator according to Fig. 6 in the region of the spherical adjustment elements;

Fig. 7 is an example of an embodiment of a terminator having a conical fit for insertion into a mount;

Fig. 8 is an example of a multiple mount for a plurality of terminators;

Fig. 8a shows the rear fastening of the terminators according to Fig. 8;

Fig. 9 is an example of an embodiment having quadratic cross-section;

Fig. 9a is a cross-section through the terminator according to Fig. 9;

Fig. 10 is an example of a terminator having rectangular cross-section and a trapezoidal plan view;

Fig. 10a is a longitudinal section through the terminator according to Fig. 10;

Fig. 10b is a cross-section through the terminator according to Fig. 10;

Fig. 11 is an example of a terminator having trapezoidal cross-section;

Fig. 11a is an example of a terminator having triangular cross-section;

Fig. 12 is an example of a terminator having honeycomb-shaped cross-section;

Fig. 13 is a modular implementation of the fibers of the fiber laser according to Fig. 1;

Fig. 14 is an example of the infeed of the pump energy into the fibers of the fiber laser according to Fig. 13;

Fig. 15 is an example of a fiber laser having two outputs;

Fig. 16 is an example of the merging of two fiber lasers;

Fig. 17 is a schematic illustration of the beam path through an acousto-optical deflector or, respectively, modulator;

Fig. 18 shows blanking out unwanted sub-beams of an acousto-optical deflector or, respectively, modulator;

Fig. 18a is an arrangement having an electro-optical modulator ;

Fig. 19 is a plan view onto a four-channel acousto-optical modulator;

Fig. 19a is a section through the modulator according to Fig. 19;

Fig. 20 is a schematic beam path for a plan view for Fig. 4;

Fig. 21 is a schematic beam path for a plan view for Fig. 4b;

Fig. 22 is a schematic beam path for a plan view for Fig. 4c;

Fig. 23 shows a beam path for terminators that are arranged at an angle

relative to one another;

Fig. 24 is a version of Fig. 23 that contains a multi-channel acousto-optical modulator;

Fig. 24a is a version for Fig. 24;

Fig. 25 is an intermediate imager for matching the fiber lasers or, respectively, their terminators to, for example, the modulator;

Fig. 26 shows the merging of twice four tracks of the beam path from terminators with a strip mirror arrangement;

Fig. 26a is a plan view for Fig. 26;

Fig. 27 is a view of a strip mirror;

Fig. 27a is a sectional drawing through the strip mirror according to Fig. 27;

Fig. 27b is another example of a strip mirror;

Fig. 28 shows the combining of twice four tracks of the beam bundle from terminators with a wavelength-dependent mirror;

Fig. 28a is a plan view of Fig. 28;

Fig. 29 is an arrangement of a plurality of terminators in a plurality of tracks and in a plurality of planes;

Fig. 30 is an arrangement of a plurality of terminators in a bundle;

Fig. 31 is a sectional view through the beam bundle from the terminators of the fiber lasers F1 through F3 according to Fig. 29 or Fig. 30;

Fig. 32 is an arrangement having a plurality of terminators in a plurality of tracks and a plurality of levels having a cylindrical optics for matching, for example, to the modulator;

Fig. 33 is a modification of Fig. 32;

Fig. 34 shows a mouthpiece for the laser gun with connections for compressed air and for extracting the material released by the beam;

Fig. 35 shows a turning of the laser gun for setting the track spacings;

Fig. 36 is an illustration for generating four tracks with an acousto-optical multiple deflector or multiple modulator;

Fig. 36a is a spatial presentation of an acousto-optical multiple deflector or multiple modulators;

Fig. 36b is an expanded embodiment related to Fig. 36a;

Fig. 36c is a plan view of Fig. 36b;

Fig. 37 is an illustration for generating multiple tracks with the assistance of an acousto-optical multiple deflector or multiple modulator;

Fig. 38 is an advantageous arrangement for avoiding reflections back into the lasers;

Fig. 39 shows a lens that has coolant flowing around it;

Fig. 39a is a section through a mount for an objective lens;

Fig. 40 shows a fiber laser or a fiber that have been clearly reduced in cross-section at their exit end;

Fig. 40a is a plan view onto the end of the fiber laser or the fiber according to Fig. 40;

Fig. 40b is a side view of the fiber end wherein the axes of the emerging beam bundles proceed nearly parallel;

Fig. 40c is a side view of the fiber end wherein the axes of the emerging beam bundles overlap outside the fiber bundle;

Fig. 40d is a side view of the fiber end wherein the axes of the emerging beam bundles overlap within the fiber bundle;

Fig. 41 shows an arrangement of fiber lasers or fibers according to Fig. 40 in a plurality of tracks and levels;

Fig. 42 shows a further embodiment of the laser radiation source;

Fig. 42a shows a further embodiment according to Fig. 42;

Fig. 42b is a sectional view of Fig. 42a;

Fig. 42c is an illustration of a robot;

Fig. 43 shows a flat bed arrangement having the inventive laser beam source;

Fig. 43a is an addition to Fig. 43;

Fig. 43b is a sectional drawing through an arrangement for removing the material released during the processing;

Fig. 44 is a hollow bed arrangement having the inventive laser beam source; and

Fig. 44a shows an addition to Fig. 44.

DESCRIPTION OF THE PREFERRED EMBODIMENT

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the preferred embodiment illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended, such alterations and further modifications in the illustrated device, and such further applications of the principles of the invention as illustrated therein being contemplated as would normally occur to one skilled in the art to which the invention relates.

Fig. 1 shows a laser radiation source 1 that is composed of a plurality of diode-pumped fiber lasers 2, also called fiber lasers, inventively implemented preferably as modules, these being charged with electrical energy by a preferably modular supply 32 that is largely converted into laser radiation. Further, a controller 33 is provided via which the modulation of the radiation is undertaken and that provides to the interaction of the laser radiation source with its periphery. The output rays of the laser enter into an optical unit 8 at the radiation entry 9 and emerge from the optical unit at the radiation exit 10. The job of the optical unit 8 is to shape the laser radiation to form a processing spot 24 on a processing surface 81; however, the laser radiation can also be directly directed on to the processing surface without the optical unit.

Figs. 2 and 2a show the fundamental structure of a fiber laser arrangement 2. In Fig. 2, the energy of a pump source such as, for example, a laser diode, called a pump source 18 here, is shaped via an infeed optics 3 to form a suitable pump spot 4 and is coupled in to the laser fiber 5. Such pump sources are disclosed, for example, in German Patent Application P 196 03 704 of the

assignee. Typical pump cross-sections of the laser fibers lie approximately between 100 μm and 600 μm in diameter given a numerical aperture of approximately 0.4. The laser fiber 5 is provided with an infeed mirror 7 at the infeed side 6 that allows the pump radiation to pass unimpeded but which exhibits 100% reflection for the laser radiation. The infeed mirror 7 can be secured to the fiber end with a suitable mount or by gluing; however, it can also be realized on the fiber end by direct vapor-deposition of a suitable layer as employed given infeed mirrors for lasers. An outfeed mirror 12 that is partially reflective for the laser radiation is attached to the outfeed side 11 of the laser fiber 5, the laser radiation 13 being coupled out through the outfeed mirror 12. Advantageously, the outfeed mirror exhibits 100% reflection for the pump radiation. As a result thereof, the remaining pump radiation is reflected back into the optical fiber, which is advantageous since the pump energy is utilized better and, further, does not represent a disturbing factor in the application of the laser radiation. The outfeed mirror can, like the infeed mirror, likewise be produced by vapor-deposition.

The infeed event of the pump radiation into the pump cross-section 14 of the laser fiber 5 is shown in greater detail in Fig. 2a. The energy in the pump spot 4 excites the laser radiation in the core 15 of the laser fiber 5 on its way through the fiber. The pump core 16 is surrounded by a cladding 17. The core of the laser fiber that is approximately 5 μm through 10 μm thick is doped mainly with rare earths.

The relatively large pump cross-section 14 simplifies the infeed of the pump energy and enables the use of a connection between pump source and laser fiber that is simple to release, as shown in Figs. 13 and 14. The terminator of the laser fiber at the side of the pump source can thereby be advantageously structurally the same as the terminator at the outfeed side; however, it need not be. A precise plug-type connection between pump source and laser fiber offers considerable advantages in the manufacture of the fiber laser and in case of service. The laser fiber, however, can also be firmly connected to the pump

source to form a laser module. As a result of the intentionally manufactured, extremely small fiber core diameter, the fiber laser supplies a practically diffraction-limited laser radiation 13 at the exit.

Fig. 3 shows a cross-section through one of the inventive embodiments of an arrangement for processing materials with the inventive laser radiation source 1. A drum 22 is rotatably seated in a housing 21 and is placed into rotation by a drive (not shown). A laser gun 23, which is conducted along the drum in the axial direction with a carriage (not shown), is located on a prism (likewise not shown).

The laser radiation emerging from the laser gun 23 impinges the surface of the drum at the processing location in the processing spot 24. Either the surface of the drum as well as a material clamped onto the drum surface can be processed. The fiber lasers, whose laser fibers 5 are respectively wound to a form, for example, an air-permeated coil 25, are supplied into the laser gun 23 with the inventive terminators 26, 94. Advantageously, however, passive single-mode fibers or other passive optical fibers, referred to in brief as fibers 28, can also be welded to the fiber lasers or coupled thereto in some other way before the terminators 26, 94 are attached, as described in Figs. 15 and 16.

The pump sources 18 of the fiber lasers are attached on a cooling member 27 that diverts the waste heat via a cooling system 31. The cooling system 31 can be a matter of a heat exchanger that delivers the waste heat to the surrounding air; however, it can also be a matter of a cooling unit. The laser gun 23 can also be connected to the cooling system, but this is not shown. The driver electronics for the pump sources 18, which belong to the supply 32 (not shown in further detail), are preferably situated on the cooling member. A machine control is provided for the drives but is not shown in Fig. 3. The structure of the pump sources, fiber laser and corresponding power electronics is preferably modularly implemented, so that corresponding pump sources and power modules of the driver electronics that are separate or combined into groups belong to the individual fiber lasers, these being capable of being connected to one another via a bus system. As explained in greater detail in Fig. 13 and Fig. 14, the laser fibers 5 and the pump

sources 18 can be connected to one another via a releasable connection. It is also possible to couple a slight part of the pump radiation out of the laser fiber 5, for example as a result of a slight injury to the cladding 14, and to conduct this via an optical fiber onto a measuring cell in order to offer a signal therefrom that can be employed for the control or, respectively, regulation of the pump radiation.

The modulation signals for the laser radiation are generated in the controller 33 and the interaction of the laser radiation source with the machine control and with the supply 32 as well as the executive sequence of the calibration events as well as of the control and regulation events are managed in the controller 33. A safety circuit (not shown), for example, switches the pump sources permanently off when there is danger.

Although a horizontally seated drum is shown in Fig. 3, the drum can be arranged in any arbitrary attitude since the inventive laser radiation source is completely directionally insensitive in terms of its attitude and is very compact in terms of structure and, moreover, since the laser fibers 5 of the fiber laser or fibers 28 coupled to the laser fibers can be arbitrarily laid; for example, the shaft of the drum can also be seated vertically or inclined from the perpendicular, which yields an especially small floor space. As a result thereof, moreover, the operation of a plurality of arrangements or a system having a plurality of drums is possible on the same floor space as would be required by an arrangement having a horizontally seated drum. As a result thereof, the printing forms can be manufactured faster; in particular, all printing forms for a color set can be produced in a single, parallel pass, which is advantageous especially with respect to the uniformity of the final result. Further, an automatic charging with printing forms for provision with images can be realized better given a system erected on a small floor space than given a spatially larger system. One or more laser radiation sources and, additionally, one or more further lasers can be directed onto the same printing form in order to accelerate the production thereof. One advantage of the multi-track arrangement having the very fine and precise tracks is that potential seams are clearly less disturbing then when recording is carried out with coarser

tracks. As described under Fig. 37, further, the position of the tracks can be precisely re-adjusted, so that residual errors become clearly smaller than a track width. The inventive laser radiation sources can thereby be preferably utilized for processing the finer contours and the further laser or lasers can be utilized for processing rougher contours, which can be particularly employed given printing forms that, for example, are composed of plastic or rubber.

Instead of one or each of the provided fiber lasers 2, it is conceivable to provide a laser system with a terminator into the laser radiation source and alternative supply to the laser gun 23, whereby the fiber laser described in detail under Fig. 2, however, represents the more cost-beneficial solution. When processing materials, namely, if the radiant power of a plurality of lasers that are not coupled to one another and that naturally emit with a slight wavelength difference are directed onto a processing spot, a phase equality of the individual lasers can be foregone and an expensive control and regulation technology for a phase coupling that is susceptible to malfunction can be avoided.

Such a laser system that, for example, is disclosed by US-A-5,694,408 contains an optical post-amplification and comprises a radiation output composed of a fiber. A terminator is described in greater detail later in one of the Figures 5, 5a, 5b, 5c, 6, 6a, 7, 9, 9a, 10, 10a, 10b, 11, 11a or 12.

Instead of employing the laser system disclosed by US-A-5,694,408, it is also conceivable to employ a phase-coupled laser system according to US-A-5,084,882. An image of the fiber bundle then results on the processing surface as the respective processing spot. Alternatively, a single-mode fiber could be welded to each fiber at the exit of the bundle, this being provided with the respective terminators, and supply the laser gun. However, it is extremely difficult and complicated to manufacture such phase-coupled laser systems and they would be correspondingly expensive. Up to now, such phase-coupled laser systems have also not been commercially available.

Fig. 4 is a section through an applied example of a laser gun having sixteen fiber lasers that are coupled via terminators 26 and having a modulation

unit composed of two multi-channel acousto-optical modulators 34. The laser gun is a multi-part receptacle for the adaptation of the optical unit and contains mounts 29 (Fig. 4a) with fitting surfaces for the fits of the terminators 26, means for combining the individual laser beams, the modulation unit, a transmission unit for the transmission of the laser radiation that is intended to produce a processing effect onto the processing surface, and an arrangement for neutralizing the laser radiation that is not intended to produce a processing effect. An arrangement for removing the material eroded from the processing surface can be arranged at the laser gun; this, however, can also be arranged in the proximity of the processing surface in some other way.

Fig. 4a shows a perspective illustration relating to Fig. 4.

Fig. 4b shows a modification of Fig. 4 wherein the beam bundle of the individual fiber lasers do not proceed parallel as in Fig. 4 but at an angle relative to one another; this, however, cannot be seen from the sectional view in Fig. 4b and is therefore explained in greater detail in Figs. 21, 22 and 24.

Fig. 4c shows a modification of Fig.4b that enables an advantageous, significantly more compact structure as a result of a differently implemented transmission unit.

Fig. 4 shall be explained in detail first with the assistance of Fig. 4a. These explanations apply analogously to Figs. 4b and 4c.

In a housing 35, 4 fiber lasers F_{HD1} through F_{HD4}, F_{VD1} through F_{VD4}, F_{HR1} through F_{HR4}, F_{VR1} through F_{VR4} via terminators 26 with mounts 29 (Fig. 4a) are arranged in respectively four tracks of one beam packet, being arranged side-by-side in a plane. The embodiment of the terminators 26 employed in Fig. 4 is described in greater detail in Fig. 9. The terminators should preferably be inserted gas-tight into the housing 35, to which end seals 36 (Fig. 4a) can be employed. Instead of the terminators shown in Figs. 4 and 4a, differently shaped terminators can also be employed, as described in Figs. 5, 5a, 5b, 5c, 6, 6a, 7, 9, 9a, 10, 10a, 10b, 11, 11a and 12, when corresponding mounts 29 are provided in the housing 35. However, as also described under Fig. 3, single-mode fibers or other fibers 28

can be attached to the fiber lasers before the terminators 26 are attached. However, an arrangement of the laser fibers 5 or fibers 28 according to Figs. 40, 40a, 40b, 40c, 40d and 41 can also be employed. For example, the fiber lasers F_{HD1} through F_{HD4} or, respectively, F_{VR1} through F_{VR4} should have a different wavelength than the fiber lasers F_{VD1} through F_{VD4} or, respectively, F_{HR1} through F_{HR4}. For example, F_{HD1} through F_{HD4} and F_{VR1} through F_{VR4} should have a wavelength of 1100 nm whereas F_{VD1} through F_{VD4} or, respectively, F_{HR1} through F_{HR4} should have a wavelength of 1060 nm, which can be achieved by a corresponding doping of the laser-active core material of the laser fibers 5. However, all fiber lasers can also exhibit different wavelengths when they are correspondingly compiled.

As explained in greater detail in Figs. 28 and 28a, the beam packets of the fiber lasers F_{HD1} through F_{HD4} are united with those of the fiber lasers F_{VD1} through F_{VD4} and the beam packets of the fiber lasers F_{VR1} through F_{VR4} are united with those of the fiber lasers F_{HR1} through F_{HR4} to form a respective beam packet F_{D1} through F_{D4} as well as F_{R1} through F_{R4} (Fig. 4a) via wavelength-dependent mirrors 37 as means for the combining. There are also other possibilities of influencing the wavelength of the fiber lasers; for example, wavelength-selecting elements such as Brewster plates, diffraction gratings or narrowband filters can be introduced in the region of the laser fibers between infeed mirror 7 and outfeed mirror 12. It is also possible to provide at least one of the two laser mirrors 7 or 12 with a mirror layer of a type that is adequately highly reflective only for the desired wavelength. The inventive execution of the beam merging, however, is not limited to the employment of fiber lasers with different wavelengths. In addition to fiber lasers that have no privileged direction in the polarization of the laser emission that is output, fiber lasers can also be employed that output a polarized laser emission. When the wavelength-dependent mirror is replaced by a mirror that is polarization-dependent such that it allows one polarization direction to pass whereas it reflects the other polarization direction, only two differently polarized laser types need be employed in order to unite the two with the

polarization-dependent mirror. In this case, the employment of the terminator 26 according to Fig. 9 having a quadratic cross-section is especially suitable, since the one or the other polarization direction can be respectively produced with the same fiber laser by turning the terminator by 90° before being mounted into the housing 35.

A particular advantage of the combining of a plurality of lasers to form a single spot, namely to each of the individual processing points B_1 through B_n (for example B_1 through B_4 in Figs. 20 through 22) is that a higher power density is achieved given a predetermined spot size on the processing surface 81.

The laser emission of the individual fiber laser can also be distributed onto a plurality of terminators, this being described in Fig. 15. This is particularly useful when materials are to be processed that manage with a low laser power or when the power of an individual fiber laser is adequately high. In such a case, it is conceivable that a laser gun 23 is equipped with only four terminators, for example F_{HD1} through F_{HD4}, for this purpose, F_{HD1} and F_{HD2} thereof, for example, being supplied by one fiber laser and F_{HD3} and F_{HD4} being supplied by a further fiber laser according to Fig. 15. When the principle described in Fig. 15 is applied twice, all four tracks F_{HD1} through F_{HD4} can be supplied by one fiber laser, this leading to an extremely cost-beneficial arrangement, particularly since further component parts such as wavelength-dependent mirrors and strip mirrors can be eliminated and, thus, an especially economical embodiment of the laser radiation source can be created.

By omitting fiber lasers or, respectively, tracks, further, the acquisition costs for such an arrangement can be lowered as needed and fiber lasers can be retrofitted later as needed. For example, one can begin with one fiber laser and one track. The lacking terminators of the fiber lasers that are not introduced are replaced for this purpose by structurally identical terminators that, however, do not contain a through opening and no laser fibers and only serve for termination in order to close the housing 35 as though it were equipped with all terminators.

However, the laser radiation of a plurality of fiber lasers can also be combined and conducted into a single terminator, this being described in Fig. 16. For example, one can work with a plurality of fiber lasers combined in this way and with one track when, as described, the missing terminators are replaced by structurally identical terminators that, however, do not contain a through opening and no laser fibers in order to close the housing 35 as though it were equipped with all terminators.

Immediately after the beam bundle has left the respective terminator, a part of the laser emission can be coupled out via a beam splitter (which, however, is not shown) and can be conducted onto a measuring cell that is not shown in the Figs. in order to produce a measured quantity therefrom that can be used as comparison value for a control of the output power of each and every fiber laser. However, laser emission can also already be coupled out of the laser fiber for the acquisition of a measured quantity before the terminator, this also not being shown.

The plurality of planes wherein the terminators are arranged is not limited to the one plane as described. For example, arrangements having three planes are recited in Figs. 29, 32, 33 and 41. An arrangement having two planes is shown in Fig. 38.

The respective beam packets of the fiber lasers are modulated via a respective four-channel acousto-optical modulator 34 whose functioning and embodiment is explained in greater detail in Figs. 17, 18, 19 and 19a. Using the acousto-optical modulator 34, which is a deflector in terms of principle, the unwanted energy in the case illustrated here is deflected out of the original beam direction I_0 into the beam direction I_1 (Fig.4a), so that it can be simply intercepted later in the beam path and neutralized. The modulation can preferably occur digitally, i.e. a distinction is made between only two conditions in the individual modulator channels, namely "on" and "off", this being especially simple to control; however, it can also occur in analog fashion since the laser power in each modulator channel can be set to arbitrary values. The modulation is not limited

thereto that the energy from the beam direction I_0 is employed for the processing and the energy from the direction I_1 is neutralized. Figs. 36, 36a, 36b, 36c and 37 recite examples wherein the beam direction 1_1 that is diffracted off is employed for processing and the energy from the direction I_0 is neutralized. Further, a slight part of the modulated radiant power of the individual modulator channels can be forwarded onto a respective measuring cell via a beam splitter (not shown) in order to generate a measured quantity that is used as a comparison value in a control circuit for the exact regulation of the laser energy of each track on the processing surface.

The multi-channel acousto-optical modulator 34 is preferably secured on a cylindrical modulator housing 41 that is rotatably seated in an opening 48 in the housing 35. After the modulator housing has been adjusted to the required Bragg angle α_B, the modulator housing is fixed with a connection 42. A seal 43 sees to it that each modulator housing terminates gas-tight relative to the housing 35. A specifically prepared printed circuit board 171 projects from the modulator housing 41 into the interior space 44 of the housing 35, electrical connections to the piezo-electric transducers 45 being produced thereover. The preferred embodiment of the modulators is described in greater detail in Figs. 19 and 19a.

After passing through the acousto-optical modulators, the beam packets F_{D1} through F_{D4} and F_{R1} through F_{R4} are conducted to a strip mirror 46 that is described in greater detail in Figs. 26, 26a, 27, 27a and 27b. The beam packet F_{D1} through F_{D4} is arranged with respect to the strip mirror 46 such that it can pass through the strip mirror unimpeded. The laser beam bundles of the beam packet F_{R1} through F_{R4}, however, are offset by half a track spacing compared to the beam packet F_{D1} through F_{D4} and impinge the strips of the strip mirror arranged in strip-shaped fashion. As a result thereof, they are redirected in terms of their direction and now lie in one plane with the laser beam bundles F_{D1} through F_{D4}. An eight-track arrangement thus derives, whereby two lasers of different wavelengths are also superimposed in each track, so that a total of sixteen lasers have been merged and take effect. The beams I_1 that have been diffracted off in the acousto-optical

modulator 34 are located above this plane I_0. Given a different adjustment of the acousto-optical modulator 34, the rays that are diffracted off can also lie under the plane of I_0, as shown in Figs. 4b and 4c.

A significant advantage of the inventive arrangement is that the symmetry axis of the beam packets F_{HD1} through F_{HD4} and F_{D1} through F_{D4} lie on the axis of the housing 35 that is defined by the bore 47, and the beam axes of the corresponding beam packets respectively lie parallel or at a right angle to this axis, which allows a simple and precise manufacture. However, it is also possible to arrange the beam packets asymmetrically and at different angles. Further, it is possible to correct small differences in the position of the beam packets by adjusting the wavelength-dependent mirrors 37 and of the strip mirror 46. It is possible to still re-adjust the terminators in position after they are mounted and in terms of their angular allocation, for example for individual optimization of the Bragg angles in the individual channels; this, however, is not shown in the Figures.

It lies within the scope of the invention that the plurality of tracks is reduced but can also be increased further; for example, by joining respectively eight instead of four terminators that are connected to fiber lasers to form a beam packet, a doubling of the number of tracks can be undertaken. For this purpose, two eight-channel acousto-optical modulators would have to be utilized. Acousto-optical modulators having 128 separate channels on a crystal can be commercially obtained.

Within the framework of the invention, it is likewise possible to arrange the fiber lasers in different planes for increasing the power per track and to superimpose their power on the processing surface, this being explained in greater detail in Figs. 29, 31, 32, 33 and 41 and/or to arrange a plurality of fiber lasers in bundles in order to superimpose their energy on the processing surface, this being described in Figs. 30 and 31.

Another possibility for increasing the number of tracks is described in Fig. 37.

Directly modulatable fiber lasers can also be utilized, this being described in greater detail in Fig. 23. In this case, the acousto-optical modulators are omitted and an especially simple structure derives.

Operation with a plurality of tracks of lasers and a plurality of lasers in a track enables high processing speeds given low relative speed between the laser gun and the workpiece. The processing speed can also thus be optimally adapted to the time constant of the heat absorption of the material. Given a longer operating time, too much energy uselessly flows off into the environment.

The housing 35 is closed gas-tight with a cover and a seal, neither being shown in the Figures. A cylindrical tube 51 is flanged to the housing 35 in the region of the bore 47 and is sealed via a seal 52. The cylindrical tube contains as an optical transmission unit two tubes 53 and 54 each having a respective optical imaging system that image eight laser beam bundles F_{D1} through F_{D4} and F_{R1} through F_{R4} at the radiation exit 10 (Fig. 1) onto the processing surface in the correct scale. Two optical imaging systems are preferably arranged following one another, since an extremely great structural length or a very small distance between the objective lens and the processing surface would otherwise derive, both being disadvantageous since a long beam path must be folded with mirrors and too small a spacing between objective lens and processing surface could lead to a high risk of contamination for the objective lens.

The beam path is shown as a side view in Fig. 4. The fundamental beam path is shown in Fig. 20 as a plan view for the beam packet F_{HD1} through F_{HD4}. The wavelength-dependent mirrors, the modulators and the strip mirrors are not shown therein. The Figures mainly show plano-convex lenses; however, it is also possible to utilize other lens forms such as, for example, biconvex or concave-convex lenses or lenses having an aspherical shape in all figures. Lens systems that are respectively composed of a plurality of lens combinations can also be employed.

In order to transmit the laser energy as efficiently as possible and keep the heating of the optical components within limits, all optical surfaces occurring in

the various embodiments of the laser radiation source are anti-reflection coated with outmost quality for the wavelength range coming into consideration. The optical imaging systems can preferably be telecentrically implemented.

There are also other advantageous solutions for the transmission unit in order to shorten the structural length of the transmission unit and thereby nonetheless achieve a large spacing between the objective lens and the processing surface, as is shown in even greater detail in, among others, Figures 4b and 4c. The lenses 55 and 56 can be connected to the tube 53 by screwed connections or by gluing; however, they can also be preferably metallized at their edges and soldered to the tube 53. The same is true of the lenses 57 and 61 in the tube 54. A gas-tight seal of the lenses and a good heat transmission from the lenses to the tubes thus derives. The tube 54 is preferably terminated gas-tight relative to the cylindrical tube 51 with a seal 62. With respect to tightness and cleanliness, the same conditions apply to the space 63 as apply to the space 44 and, likewise, to the spaces 64 and 65 within the tubes 53 and 54. The chambers 66 and 67 are preferably connected to the spaces 44 and 63 via bores 71. The tubes 53 and 54 can preferably comprise openings 72.

An intercept arrangement 73 for neutralizing the laser radiation that is not intended to produce any processing effect on the processing surface and that comprises a high-reflectivity mirror 74 and a dispersion lens (concave lens) 75 projects into the space 63. The principle of the intercept arrangement 73 is described in greater detail in Fig. 18. The intercept arrangement 73 is introduced with a seal 76, and the concave lens 75, which can also be replaced by some other optical element, for example a glass plate, is glued into the intercept arrangement or is preferably metallized at an image edge zone and soldered to the intercept arrangement for better heat elimination. The space 63 is thus closed off gas-tight from the environment. What derives as a result of the described techniques is that the entire interior of the laser gun is sealed gas-tight from the environment. The spaces 44, 63, 64 and 65 and the chambers 66 and 67, i.e. the entire interior of the laser gun, can be preferably evacuated or filled with a protective atmosphere. The

spaces and chambers should be as free as possible of components that output gases or particles because dirt could otherwise settle on the highly stressed optical surfaces, which would lead to a premature failure of the arrangement. The seals to be employed should not give off any particles or gases. Ultimate cleanliness of the parts to be assembled and of the environment has great value associated with it during assembly until the laser gun has been closed. After the closing of the laser gun 23, an evacuation of the entire interior can be undertaken via the valve 77 or a protective atmosphere can be filled in. The advantage of filling the interior with protective atmosphere is that it is simpler to replenish in that a gas bottle (not shown) is connected to the valve 77 during operation via a pressure-reducing valve, gas being capable of being refilled into the housing therefrom as needed. Another advantage is that, when a terminator is to be removed from the housing for the replacement of a fiber laser and is to be replaced by another or when the housing or, respectively, the cylindrical tube must be opened by the user for some reason or other, a slight quantity of the protective atmosphere can be allowed to flow through the housing during the procedure in order to thus prevent the penetration of dirt particles into the protected space. A slight quantity of the gas can also be allowed to constantly flow through the housing and escape such through openings, preferably in the proximity of the objective lens. This flow also prevents a contamination of the objective lens by dirt particles that are released during the processing event (Fig. 39a). The evacuation or the filling with protective atmosphere can also be foregone when a shorter service life of the laser radiation source is accepted.

It is advantageous in the arrangement according to Fig. 4 that the angle between the beam packets of the original beam direction I_0 of the acousto-optical modulator and the beam direction I_1 that is diffracted off is noticeably increased by the imaging system composed of the lenses 55 and 56, so that it is simple to intercept the unwanted radiation packet of the deflected beam direction with the highly reflective mirror 74 at the intercept arrangement 73. The mirror 74 is preferably fabricated of metal and is provided with a highly reflective layer in

order to keep the heating as a consequence of absorbed laser energy low. For better heat elimination, it is connected via a strong flange of the intercept arrangement 73 to the tube 51. However, the intercept arrangement can also be foregone when the highly reflective mirror is replaced with an optical component such as, for example, a lens that slightly modifies the optical properties of the laser radiation to be intercepted such that the focus of the radiation that is diffracted off is different from the focus of the radiation employed for processing the material. If the radiation to be intercepted would then also be conducted onto the processing surface, the radiation to be intercepted would not have the required power density in order to erode material but would be uselessly absorbed and reflected. The advantage of the arrangement according to Fig. 4 is that low demands are made of the optical components in the two tubes. The two tubes could also be implemented completely the same. Another advantage is that the axes of the terminators 26 lie parallel to one another. The distance between the objective lens 61 and the processing surface 81 dare not be too small, so that particles that fly off from the material surface do not proceed onto the objective lens. When it is contaminated, it then absorbs the laser energy that passes, is destroyed, and is thus unuseable. In order to prevent the contamination, a special mouthpiece 82 is arranged between the objective lens 61 and the processing surface 81, this being described in greater detail under Fig. 34.

The laser gun 23 of the laser radiation source is rotatable around the optical axis that is identical to the axis of the cylindrical tube 51, 95 within the arrangement for processing materials (Fig. 3), for example on a prism 83, and is seated displaceable in the direction of the optical axis and fixed in its position with a strap retainer 85 or with a plurality of strap retainers. As a result thereof, an exact adjustment of the laser gun to the processing surface 81 is possible. A plate 86 that comprises openings 87 through which a coolant can be pumped is located outside the prism 83. The job of this plate 86 is to intercept and divert the laser energy intercepted from the beam path of the transmission unit, this being shown in greater detail in Fig. 18. A heat dam that, however, is not shown in the

Figs., is located between the plate 86 and the tube 51, 95, 113. The plate is connected to the tube 51, 95, 113 via insulating flanges 91. The flanges 91 also prevent the emergence of laser radiation.

By turning the laser gun 23 around its optical axis, the track spacing of the laser tracks on the processing surface 81 can be modified, this being shown in greater detail in Fig. 35. It lies within the scope of the invention that the turning of the laser gun for setting the track spacing as well as the setting of its spacing from the processing surface can be implemented not only exclusively manually but with the assistance of a suitable, preferably electronic control and/or regulation. Suitable measuring devices (not shown) can also be inventively provided for this purpose, these being located in the proximity of the processing surface and being capable of being approached by the laser gun as needed. A further possibility for adjusting the track spacing is described in Figs. 36, 36a, 36b, 36c and 37. A manually or motor-adjustable vario-focusing optics can also be utilized for setting the track spacing. Such a vario-focusing optics, in addition to permanently arranged lenses, preferably has two movable lens systems, whereby an adjustment of the first lens system mainly effects an adjustment of the imaging scale, with which the track spacing can be influenced, and whereby an adjustment of the second lens system mainly effects an adjustment of the focusing. An iterative setting can be undertaken for optimizing track spacing and best focus. It is also possible to arrange a displaceable lens (not shown) having a long focal length, preferably between the lenses 57 and 61, with which the focusing of the processing points on the processing surface can be finely readjusted without having to displace the radiation source because the resultant focal length of two lenses is dependent on their spacing.

As a result of the high laser power, the optical elements in the beam path will heat, since they absorb a part, even though a slight part, of the laser energy. Preferably, the critical optical components are therefore not made of glass but of a material having better thermal conductivity, for example of sapphire. The waste heat, given metallization of the connecting surfaces of the optical components, is

eliminated by the solder connections to the mounts and to the housing. For better heat output, the housing is implemented with cooling fins 92 that can be cooled by a ventilator (not shown). A permeation of the housing 35 as well as of the other component parts of the laser radiation source with bores is also possible, particularly in the critical regions at the lens mounts and mounts for the terminators 26, a coolant being capable of being pumped therethrough, as shown in Figs. 8 and 39.

Since, as presented above, extremely high laser powers are required in processing of materials, it is critical to the invention to keep the number of optical elements, particularly lenses, in the beam path as low as possible in order to keep the optical losses and the risk of contamination of the optics, which would always lead to a premature failure, as low as possible. It is also lies within the scope of the invention that the objective lens (61, 103 and 112) is equipped with an interchangeable mount so that it can be quickly replaced by the user of the laser radiation source as needed, whether because it has been contaminated during operation or because a different imaging scale is requested. In this case, it is advantageous that the bore 72 and the tube 54 is not implemented.

It also lies within the scope of the invention that techniques are undertaken in the optical beam path so that no laser energy can proceed back into the lasers. It is shown in Fig. 3 that the laser radiation impinges the material to be processed not perpendicularly but at an angle, so that the radiation reflected at the material surface cannot proceed back into the laser radiation source. It is also shown in Figs. 4, 4b, 4c and Fig. 18 that the laser radiation to be destroyed can be conducted by an obliquely placed concave lens 75 into a sump composed of an obliquely placed plate 86 that can be cooled. Instead of the concave lens of 75, some other optical component, for example a plate or a diaphragm, can also be inventively employed. The effective diameter of this optical component is thereby dimensioned such that the laser radiation conducted into the sump can just pass, whereas radiation that is reflected back from the sump or is dispersed back, is largely retained, so that no energy can proceed back into the laser. Inventively,

the surface of the plate 86, which is shown as a planar surface in the Figures, can also be implemented crowned or hollow and can be preferably roughened in order to absorb a maximum of radiation and reflect or, respectively, disperse a minimum of radiation.

It is also shown for two planes in Fig. 38 that, as a result of a slight parallel offset of the beam axes of the beam bundles emerging from the terminator, an oblique incidence onto all effected lens surfaces can be achieved. This also applies for the arrangement having one or more planes. The acousto-optical modulator 34 is already rotated by the angle α_B relative to the axis of the beam bundle; however, it can also be additionally rotated by the angle γ relative to the symmetry axis of the beam bundle or an arrangement according to Fig. 24 can be employed wherein the axes of the ray beams emerging from the terminators proceed at an angle relative to one another. It has been shown in practice that angular differences of 1 through 2 degrees between the perpendicular onto the optical surface and the axis of the beam bundle are already adequate in order to achieve protection against radiation reflected back into the laser.

It lies within the scope of the invention to select embodiments of the optical, mechanical and electrical arrangement for Fig. 4 deviating from the described embodiment. For example, the beam packets F_{D1} through F_{D4} and F_{R1} through F_{R4} could be focused onto the processing surface by a shared lens, similar to that shown in Fig. 31, which in fact yields a very high powered density but cannot present the shape of the processing spot as well since all processing points lie on one another and are united to form a common spot.

Fig. 4b shows another inventive laser gun for a laser radiation source that differs from the laser gun shown in Fig. 4 on the basis of a housing 93, terminators 94, a cylindrical tube 95, a tube 96 and on the basis of a highly reflective mirror 97.

The housing 93 has mounts 29 fitting the terminators 94. The terminators 94 preferably correspond to those of Figs. 10, 10a and 10b; the axes of the beam bundles do not proceed parallel in the corresponding beam packets. Rather, they

proceed somewhat toward the center of the concave lens 101, which is shown in the plan view 21. However, all other terminators according to Figs. 5, 5a, 5b, 5c; 6, 6a; 7, 9, 9a; 11, 11a and 12 can also be employed when it is insured that the mounts 29 therefore are arranged at a corresponding angle. The transmission unit is located in the tube 96, this transmission unit being composed of three lenses, namely a dispersion lens, i.e. a concave lens 101, and two positive lenses, i.e. convex lenses 102 and 103, whereby the convex lens 103 is preferably implemented as an interchangeable objective lens. For the mounting of the lenses with respect to tightness and heat elimination, what was stated as to Fig. 4 and Fig. 4a applies, as it does for the selection of material with respect to the heat conduction.

The tube body 96 can be evacuated in the space between the lenses 101 and 102 or can be filled with a protective atmosphere or, preferably, be connected to the space 105 via a bore 104, said space 105 being in turn connected via a bore 106 to the space 107. The space 107 is connected to the space 111 via the bore 47, said space 111 being in turn terminated gas-tight, as described under Fig. 4 and Fig. 4a. The space between the lenses 102 and 103 can be connected via a bore (not shown) to the space 105, particularly when the mount of the objective is closed gas-tight or, as described under Fig. 4, when a slight amount of the protective atmosphere constantly flows through the laser gun and emerges in the proximity of the objective lens, this, however, not being shown in Fig. 4b. The entire interior of the laser gun, composed of the spaces 111, 105, 107, is preferably evacuated or filled with a protective atmosphere or, respectively, flooded by a protective atmosphere, as was described in detail under Fig. 4 and Fig. 4a. The undesired beam bundles are intercepted with a highly reflective mirror 97; in contrast to Fig. 4, however, no lens system is present that has an angle-enlarging effect, so that the distance between the highly reflective mirror and the modulators is kept correspondingly large here in order to achieve an adequate spatial separation of the beam packets I_0 and I_1. Nonetheless, the entire structural length of the laser gun is similar here to the arrangement of Fig. 4. The

optical beam path of the transmission unit in Fig. 4 represents a side view. Fig. 21 indicates a fundamental beam path for a plan view relating to Fig. 4b. The beam path of the lenses 101 and 102 corresponds to that of an inverted Galileo telescope; however, it can also be implemented as an inverted Kepler telescope when the concave lens 101 having a short focal length is replaced by a convex lens. Such telescopes are described in the textbook "Optik" by Klein and Furtak, Springer 1988, pages 140 through 141. The advantage of the arrangement according to Fig. 4b is that only three lenses are required for the transmission unit. The disadvantage, to wit that the ray beams of the individual terminators do not proceed parallel, is eliminated by terminators according to Figs. 10, 10a and 10b.

A lens 55 could also be employed in order to deflect the beam bundles into the desired direction, as was shown in Fig. 20. The individual laser beam bundles would then proceed parallel to one another between the terminators 26 and the lens 55, that is arranged as in Fig. 4, and no difference from Fig. 4 derives with respect to the housing and the terminators or, respectively, their arrangement. Since, however, the lens 55 also exercises a collecting effect on the individual beam bundles in addition to the deflecting effect, the same conditions as in Fig. 21 would not arise at the location of the concave lens 101. This, however, can be compensated by a different adjustment of the spacing of the fiber 28 or, respectively, of the laser fiber 5 from the lens 133 or by a modification of the lens 133 in the terminators 26, i.e. the ray cone of the laser beam bundle from the individual terminators would be respectively set such that a sharp image respectively derives on the processing surface at the location of the points B_1 through B_n.

According to the invention, it is also possible to combine the lenses 102 and 103 to form a single, combined lens. A transmission unit having only two lenses then derives. It is also possible to arrange a displaceable lens (not shown) with a long focal length between the lenses 101 and 102, the focusing of the processing points on the processing surface being capable of being finely

readjusted therewith without displacing the radiation source. A vario-focusing optics can also be employed, as was mentioned under Fig. 4.

A special mouthpiece 82 is provided at the laser gun 23 that is intended to prevent a contamination of the objective lens 112 and that is described in greater detail under Fig. 34.

Fig. 4c shows a laser gun that is even more significantly compactly implemented than that of Fig. 4 and Fig. 4a. In combination with a mirror arrangement, an objective lens 112 is employed as transmission unit and this can be interchanged for achieving different imaging scales. As already described under Fig. 4, a vario-focusing optics can also be employed. Inventively, however, an imaging can occur with the mirror arrangement by itself without additional objective lens 112.

Fig. 4c differs from Fig. 4b in terms of the following points: The cylindrical tube 95 is replaced by an eccentric tube 113. The tube body 96 is preferably replaced by a plate 114 having a concave mirror 115 and a mount 116 with an objective lens 112 and a highly anti-reflection coated plate 117. The intercept unit 73 is given an arced (convex) mirror 121 above the highly reflective mirror 97. The eccentric tube is connected to the housing 93 at one side. A seal 52 sees to the required tightness. The plate 114 is introduced into the eccentric tube 113, said plate 114 containing a passage for the beam packets I_0 and I_1 and carrying the concave mirror 115 whose dissipated heat can thus be diverted well to the eccentric tube. The eccentric tube has two axes that are preferably parallel to one another, namely, first the symmetry axis of the entering beam packets having the direction I_0 that are directed onto the arced mirror and, second, the axis between concave mirror and objective lens 112 that can be considered as an optical symmetry axis for the emerging laser radiation.

Inventively, the beam path is folded with the two mirrors 121 and 115. The arced mirror 121 is preferably fabricated of metal. It is intimately connected to the highly reflective mirror 97 and is preferably fabricated of one piece therewith. The convex surface of the arced mirror can be spherically or

aspherically shaped. The mirror 115 is concavely shaped, i.e. a concave mirror. Its surface can be spherically shaped but is preferably aspherically shaped. It is preferably composed of metal. Metal has the advantage of good elimination of the waste heat. A considerable advantage given manufacture of metal also derives in the production of aspherical surfaces, which, in this case, can be produced by known diamond polishing lathing methods, as can also spherical and planar surfaces. As a result thereof, the highly reflective mirror 97 and the arc mirror 121 can be manufactured of one piece and, preferably, in one work pass having the same shape of the surface and can be mirrored in common, which is particularly simple in terms of manufacture and very advantageous for the positional stability of the arced mirror. In the modulation of the laser energy with the acousto-optical modulator, it impinges either the arc mirror 121 or the highly reflective mirror 97. The waste heat that is produced remains the same in any case and the arced mirror stays at its temperature and, thus, its position, which is very important since it is preferably implemented with a short focal length and the imaging quality of the arrangement is therefore very dependent on its exact position. In this case, the arced mirror 121 has advantageously co-assumed the function of the highly reflective mirror 97. The highly reflective mirror 97 can, however, also have some other form of surface than the arced mirror 121 and, for example, can be a plane mirror.

The beam path is similar to that of an inverted mirror telescope after Herschel that, however, contains a convex lens instead of the arced mirror and that is described in greater detail in Fig. 22. Mirror telescopes are described on page 152 in the "Lehrbuch der Experimentalphysik Band III, Optik" by Bergmann-Schäfer, 7th edition De Gruyter 1978. The arced mirror can also be replaced by a concave mirror having a short focal length. As a result thereof, the structural length would be slightly enlarged and different ray cones of the ray bundles emerging from the terminator would have to be set in order to obtain a sharp image in the image plane. The arced mirror could also be replaced by a convex lens having a short focal length. Another folded mirror would then have

to be utilized in order to preserve the compact structure. The intercept arrangement 73 is attached gas-tight to the eccentric tube via a seal 76 the undesired laser energy, as described under Figs. 4, 4b and 18, being diverted via said intercept arrangement 73 to a cooling plate 86 with bores 87 and being neutralized. It is also possible to already intercept the undesired laser radiation from the beam packet I_1 at the location of plate 114 and neutralize it.

The space 111 in the housing 93 is connected to the cavity 123 via the bore 122. Both spaces can be evacuated, filled with a protective atmosphere, or flooded by a protective atmosphere, as already described. The mount 116 that accepts the interchangeable objective lens 112 is attached to the end of the eccentric tube 113 that resides opposite the housing 93. A seal 124 closes the cavity 123 gas-tight. The mount can also accept an anti-reflection coated plate 117 whose edge is preferably metallized and that is preferably soldered gas-tight to the mount. Its job is to keep the cavity 123 gas-tight when the objective lens was removed for cleaning or when an objective lens having a different focal length is to be introduced in order to generate a different imaging scale. The space between the objective lens 112 and the highly anti-reflection coated plate 117 can also be connected to the space 123 via bore (not shown), particularly when the entire laser gun, as described under Fig. 4, constantly has a protective atmosphere flowing through it, this emerging in the proximity of the objective lens 112, which is shown in Fig. 39a. The highly anti-reflection coated plate 117, however, can also contain optical correction functions, as known for the Schmidt optics known from the literature, in order to thus improve the optical imaging quality of the arrangement. However, it is also possible to omit the highly anti-reflection coated plate, particularly when it contains no optical correction function and the objective lens was introduced gas-tight or a protective atmosphere flowing therethrough sees to it that no dirt can enter into the space 123 when the objective lens is replaced. A special mouthpiece 82 is provided at the laser gun 23, this being intended to prevent a contamination of the objective lens 112 and being described in greater detail under Fig. 34.

The eccentric tube can be provided with cooling fins 92 over which a ventilator (not shown) can blow in order to eliminate the waste heat to the environment better. The laser gun is rotatably seated in a prism around the axis between concave mirror and objective lens in order, as described under Fig. 4, to make the track spacing adjustable and in order to set the correct distance from the processing surface 81. The laser gun can be fixed with a strap retainer 85.

It is possible to arrange a displaceable lens (not shown) having a long focal length between, preferably, the concave mirror 115 and the objective lens 112, the focusing of the processing points onto the processing surface being capable of being finely readjusted therewith without displacing the laser gun. However, a variable focusing optics (zoom lens) can also be utilized, as was described under Fig. 4. All descriptions that were provided for Figs. 4, 4a and 4b also apply analogously.

Fig. 5 shows a preferred embodiment of a terminator 26 for a fiber 28 or laser fiber 5, which is also a fiber. Plug-type connections for optical fibers for low powers are known in optical communications technology, in sensor applications and measurement technology; these, however, are not suitable for high powers because too much heating occurs, this leading to destruction. For example, such laser diode collimator systems, beam shaping optics and coupling optics are described in the catalog 1/97 of Schäfter & Kirchhoff, Celsiusweg 15, 22761 Hamburg, pages A1 through A6. However, the power of these systems is limited to 1000 mW and is thus below the demands for the desired applications in processing materials by a factor of 100 because an adequate heat elimination is not assured. Further, these systems are relatively large in diameter, so that no high packing density of the laser outputs can be achieved. Another great disadvantage is that these systems are not adequately sealed; they would get dirty very quickly and burn up due to an increased absorption of the laser radiation. Last but not least, it should also be mentioned that the precision of the mount for fibers and the lens are inadequate for the desired application. Terminators according to this patent application are therefore significantly more advantageous.

Such terminators can be advantageously employed for coupling laser radiation out of a fiber 5, 28, as disclosed in the German Patent Application P 198 40 935.4 of the assignee “Abschlussstück für Lichtleitfasern”.

This terminator 26 can be fundamentally used for all applications wherein the matter of concern is that the ray bundle emerging from a fiber 5, 28 be precisely coupled with a releasable connection. It is likewise possible with the assistance of this terminator to produce a precise, releasable connection of the fiber 5, 28 to the remaining optics. The terminator is composed of an oblong housing 132 that comprises a through cylindrical opening 130 extending in axial direction. The housing is preferably manufactured of prefabricated, for example drawn material that can preferably be composed of glass. The laser fiber 5 of the fiber laser is preferably stripped off its cladding at its ultimate end and is preferably roughened at its outside surface, this being disclosed in German Patent Application P 197 23 267, so that the remaining pump radiation leaves the laser fiber before the entry of the laser fiber into the terminator. The fiber 5, 28 can also be additionally surrounded by a single-layer or multi-layer protective sheath 131 that can be connected to the housing 132 of the terminator, for example with a glued connection 142. The housing 132 comprises fits 134 with which the housing can be exactly introduced in a mount 29 (Fig. 5a, Fig. 7, Fig. 8, Fig. 14). The fits can thereby extend over the entire length of the housing (Figs. 5b, 9, 10); however, it can also be attached in limited regions of the housing (Figs. 5, 6, 7). One or more seals 36 can be provided that, for example, are connected to the housing 132 with glue connections 142. The job of the seals is to enable a gas-tight connection of the terminators to the mounts 29. The housing can have a different diameter, for example a smaller diameter, in the region of the protective cladding 131 and of the seal 36 than in the region of the fits. At the end of the housing 132, the end of the fiber 28 or, respectively, of the laser fiber 5 is accepted and conducted within the housing in the opening 130. A lens 133 having a short focal length is secured to the other end of the housing 132, whereby the housing can comprise a conical expansion 139 so as not to imped the laser

radiation 13. Means can be provided for adjusting the position of the fiber 5, 28 within the terminator in order to adjust the position of the fiber relative to the lens 133 within the terminator and with reference to the fits 134, as shown in Figs. 5b, 5c, 6, 6a, 7, 9, 9a, 10a, 10b, 11, 11a and 12. The radial position of the fiber 5, 28 can also be defined by the cylindrical opening 130, whereby the fiber is axially displaceable within the opening. The position of the lens 133 can either be adequately precisely mounted during assembly or can be axially and/or radially adjusted and fixed with suitable means (not shown) with reference to the fiber 5, 28 and to the fits 134, whereby the fiber can also be axially displaced (Fig. 5b). The adjustments are advantageously undertaken with a measuring and adjustment device. What the adjustment is intended to achieve is that the beam bundle 144 emerging from the lens 133 is brought into a predetermined axial and focus position with a defined cone relative to the fits 134. After a fixing of the fiber 5, 28 within the housing 132 and of the lens 133 at the housing, the measuring and adjustment device is removed. Inventively, it is also possible to provide the end of the fiber 5, 28 with a suitable coating, for example a correspondingly thickly applied metallization 141, in the region of the terminator before assembly in order to further improve the durability of the adjustment. The fixing of the fiber 5, 28 within the housing 132 can occur with suitable means such as gluing, soldering or welding. An elastic compound 138 that represents an additional protection for the fiber is preferably provided at the transition between the housing 132 and the protective sheath 131. It is also inventively possible to fashion and align the lens 133 by corresponding shaping and vapor-deposition of a corresponding layer, preferably at its side facing toward the fiber end, such that it co-assumes the function of the outfeed mirror 12 for the fiber laser.

Fig. 5a shows a multiple arrangement of fiber laser outputs with the terminators from Fig. 5. Bores 150 for the acceptance of two terminators 26 for two tracks are provided in a housing 145. Further, respectively three pins 148 and 149 are attached in rows such within the housing 145 in extension of the bores that they represent a lateral limitation as mount 29 for the terminators and see to a

precise guidance and alignment of the terminators. The diameters of the pins 148 are referenced d_1 and are preferably identical to one another. The diameters of the pins 149 are referenced d_2 and are preferably likewise identical to one another. If the diameters of the pins 148 were the same as the diameters of the pins 149, the axes of the ray beams of both tracks would lie parallel to one another in the plane of the drawing since the terminators 26 comprise cylindrical fits 134. In Fig. 5a, however, the diameters of the pins 149 are shown larger than the diameters of the pins 148, this resulting in the axes of the two ray beams proceeding at an angle relative to one another in the plane of the drawing. The angle between the ray beams is dependent on the diameter difference $d_2 - d_1$ and on the center-to-center spacing M of the two pin rows. The terminators are conducted through the housing 145 at the underside in one plane and are conducted from above through a cover (not shown) of the housing that is secured to the housing and can close it gas-tight with a seal (not shown). The housing 145 can be part of a receptacle for an optical unit for shaping the laser radiation. The terminators are secured to the housing 145 with clips 147 and screws (not shown), whereby the seals 36 see to a gas-tight closure. The arrangement is not limited to two tracks; further bores 150 can be provided and further pins 148 and 149 can be introduced in order to insert further terminators for further tracks. The arrangement is not limited to the one plane as described; further bores 150 can be inserted into the housing 145 in further tracks and in one or more further planes, these lying above or below the plane of the drawing, and the pins 148 and 149 are lengthened to such an extent that they represent mounts 29 for all tracks and all planes. Inventively, pins 148 and 149 are likewise employed for producing a defined spacing between the planes. In this case, the pins proceed horizontally between the terminators. For example, the horizontally arranged pins 149 proceed between the wall of the housing 145 wherein the bores 150 lie and the row of illustrated, vertically arranged pins 149. The horizontally arranged pins 148 preferably proceed at a spacing M parallel to the horizontally arranged pins 149. Horizontally arranged pins are not shown in Fig. 2a. The pins 148, 149 are preferably fabricated of

drawn steel wire; however, they can also be composed of other materials, for example of drawn glass. An advantage given the arrangement with a plurality of tracks and/or planes in the illustrated way is that the pins 148, 149 exhibit a certain flexibility. As a result thereof, it is possible to press the entire packet of the terminators together in the direction of the tracks and in the direction of the planes such that the terminators 26 with their fittings 134 lie against the pins without spacing, this being desirable for achieving utmost precision.

Fig. 5b shows a terminator 26, whereby means for adjusting the position of the fiber 5, 28 within the terminator are provided in order to be able to adjust the position of the fiber 5, 28 relative to the lens 133 within the terminator and with respect to the fittings 134. The position of the lens can also be adjusted. The adjustments are advantageously undertaken with an adjustment device. Adjustment screws 135, 136 (Figs. 5b, 5c, 9, 9a, 10a, 10b, 11, 11a, 12) and/or balls 137 (Figs. 6, 6a, 7) can be provided for the adjustment of the position of the fiber 5, 28 in the housing 132. The fiber 28 or laser fiber 5 can also be axially displaced within the adjustment screws 135, 136 or balls 137. The position of the lens 133 can either be adequately precisely mounted during assembly or axially and/or radially adjusted and fixed by means (not shown) with reference to the fiber 5, 28 and with reference to the fittings 134, whereby the fiber can also be axially displaced. The adjustments are advantageously undertaken with a measuring and adjustment device. What the adjustment is intended to achieve is that the beam bundle 144 emerging from the lens 133 is brought into a predetermined axial and focus position with a defined cone on the basis of a relative adjustment of lens 133 and fiber 5, 28 toward the fits 134. After a fixing of the fiber 5, 28 within the housing 132 and of the lens 133 to the housing, the measuring and adjustment device is removed. That stated under Fig. 5 for this and the other embodiments continues to apply, for example regarding the metallization 141, the elastic compound 138 and the employment of the lens 133 as laser mirror.

Fig. 5c shows a cross-section through the terminator 26 in the region of the adjustment screws, from which it can be seen that preferably three adjustment screws 135 are provided distributed over the circumference, the fiber 28 or, respectively, the laser fiber 5 being adjustable in fine fashion in the housing therewith. Further, further adjustment screws 136, as shown in Fig. 5b, can be provided within the terminator at the end of the terminator at which the fiber 28 or, respectively, the laser fiber 5 enters. These adjustment screws are designed like the adjustment screws 135. When only one set of adjustment screws 135 is employed, the fiber 28 or the laser fiber 5 can only be adjusted with respect to the angle. When two sets of adjustment screws are employed, they can also be displaced parallel to their axis. The fixing of the fiber 5, 28 within the housing 132 can occur with suitable means such as gluing, soldering or welding.

Fig. 6 shows an embodiment of the terminator 26 wherein small balls 137 of metal or, preferably, metallized glass are employed instead of adjustment screws, these being brought into their position in the housing and being subsequently glued or soldered. A plurality of sets of balls can also be applied.

Fig. 6a shows a cross-section through the terminator in the region of the balls 137.

In order to prevent the optical surfaces on the optical fiber and the side of the lens 133 that faces toward the optical fiber from contaminating biparticles in the ambient air, the connections in Figs. 5, 5b, 5c, 6, 6a, 7, 9, 10, 11, 11a and 12 between the lens 133 and the housing 132 as well as between the adjustment screws 135 and 136 or, respectively, the balls 37 and the housing 132 can be hermetically closed. This can occur with suitable glued or soldered connections 142. When a soldered connection is preferred, the glass parts are previously metallized at the corresponding locations 141. In order to achieve a greater strength, the glued or soldered connections can also entirely or partially fill the remaining gap between the fiber 28, the laser fiber 5 and the housing 132, or the protective sheath 131 in the proximity of the terminator, this being shown, by way

of example, in Fig. 5. It is also possible to durably evacuate the interior 143 of the housing or fill it with a protective atmosphere.

Fig. 7 shows a further embodiment of a terminator 26 that is introduced in a housing 145 with a mount 29. Given this embodiment, the front, outer fitting 134 in the region of the lens 133 is conically implemented for better sealing and for better heat elimination. Additionally, a seal 146 can be provided that instead of being attached to the lens-side end of the terminator as shown, can also be attached to the fiber-side end thereof.

Fig. 8 shows mounts 29 in a housing 145 for a plurality of conically implemented terminators 26 according to Fig. 7. Such mounts are advantageous when a plurality of outputs of fibers or fiber lasers are to be arranged next to one another or next to one another and above one another. The axes of the mounts can thereby be arranged such that the axes of the beam bundles emerging from the terminators of the terminators lying side-by-side and/or above one another proceed parallel to one another or at an angle. In order to eliminate the waste heat, the housing 145 can be inventively provided with bores through which a coolant is conducted.

Fig. 8a shows the rear fastening of the terminators 26 in the housing 145. For fixing the terminators 26, 94, clips 147 are provided that fix the ends of the terminators with screws 151 in the housing at the locations at which the fibers respectively enter into the housing of the terminators 26, 94.

Fig. 9 shows an embodiment of a terminator 26 having a quadratic or rectangular cross-section, whereby all outside surfaces lie opposite one another proceed parallel and can be fittings 134. Fig. 9a shows a cross-section through the terminator 26 according to Fig. 9 having a quadratic cross-section.

Fig. 10 shows an embodiment of the terminator 94 with rectangular cross-section, whereby two outside surfaces lying opposite one another proceed trapezoidally and two outside surfaces lying opposite one another proceed parallel to one another. The outside surfaces can be fittings 134.

Fig. 10a shows a longitudinal section and Fig. 10b a cross-section through the terminator according to Fig. 10.

Fig. 11 shows terminators 26 having trapezoidal cross-sections, so that a row of terminators arises by successive turning of the terminators by 180° when a plurality of terminators are joined to one another, whereby the center points of the terminators lie on a central line. When desired, a plurality of such rows can be arranged above one another, which is indicated with broken lines in Fig. 11.

Fig. 11a shows terminators 26 with a triangular cross-section that can likewise be arranged in a plurality of rows above one another, this being indicated with broken lines.

Fig. 12 shows terminators 26 having a hexagonal cross-section that can be arranged honeycomb-like for increasing the packing density.

The inventive terminators advantageously enable the laser radiation source to be built of individual modules.

Fig. 13 shows an applied example of the terminator 26 or 94 given a fiber 28 or a laser fiber 5 that have both ends provided with a respective, inventive terminator.

According to the invention, it is possible to preferably implement the lens 133 at its side facing toward the fiber end on the basis of a corresponding shape being and vapor-deposition of a corresponding layer such that it co-assumes the function of the outfeed mirror 12. According to the invention, it is also possible to implement the lens 3, 154 by corresponding shaping and vapor-deposition of a corresponding layer that it co-assumes the function of the infeed mirror 7.

It is fundamentally possible to combine a plurality of the terminators described above in a plurality of tracks side-by-side and above one another in a plurality of planes to form a packet.

It is also possible to implement the shape of the terminators differently from that shown in the Figures, for example that a cylindrical shape according to Fig. 6 is lent trapezoidal or rectangular fits according to Fig. 9 or Fig. 10.

Fig. 14 shows a coupling of the laser fiber 5 to a pump source with the terminator 26 via the housing 152 in which the pump source 18 is accommodated in a recess 153, preferably gas-tight. A seal 146 assures that the terminator 26 likewise terminates gas-tight, so that no dirt particles can penetrate into the recess from the outside and, as needed, it can be evacuated or filled with a protective atmosphere. A constant current of a protective atmosphere can also flow through the recess 153, particularly given temporary removal of the terminator 26. The radiation of the pump source 18 is focused onto the pump cross-section of the laser fiber 5 via a lens 154. The pump source can be composed of one or more laser diodes; however, it can also be composed of an arrangement of one or more lasers, particularly fiber lasers as well, whose output radiation was united such with suitable means that a suitable pump spot arises.

Fig. 15 shows the branching of the output radiation from the laser fiber 5 of a fiber laser with a fused fiber coupler 155. Such fused fiber couplers are described for single-mode fibers on Page G16 of the catalog of Spindler and Hoyer specified in greater detail under Fig. 20 and can be directly fused to the output of the laser fiber 5 after correspondingly precise alignment. In this case, thus, the terminator 26, 94 is connected to a passive single-mode fiber or, respectively, to a different fiber 28 and not directly to a fiber laser with the active laser fiber 5. There are also other possibilities of splitting the laser beam into a plurality of sub-beams such as, for example, beam splitter mirrors or holographic beam splitters. The advantage of the described fused fiber coupler, however, is that the laser radiation can be brought to the processing point guided within fibers insofar as possible, this leading to a considerable simplification of the arrangement.

Fig. 16 shows the uniting of the radiation from the laser fibers 5 of two fiber lasers via a fused fiber coupler 156. The cross-sections of the two input fibers are united to form one fiber in the fused fiber coupler 156. For example, the diameter of the fibers at the two inputs of the fused fiber coupler amounts to 6 μm and the core diameter of the two laser fibers to be fused on likewise amounts

to 6 µm. A core diameter of the single-mode fiber at the output of the fused fiber coupler thus becomes 9 µm, which still allows a faultless guidance of a single mode for the corresponding wavelength. The diameter at the output of the fused fiber coupler, however, can also be greater than 9 µm, and more than two outputs of fiber lasers or, respectively, fibers can be united. The terminator 26, 94 in this case is thus connected to a passive single-mode fiber or other passive fiber 28 and not to a fiber laser with the active laser fiber 5.

However, all other types of light waveguides can be welded to the fiber laser or coupled thereto in some other way, for example via optics.

One or more passive single-mode fibers or one or more other passive fibers 28 can also be coupled to an individual fiber laser instead of a brancher according to Fig. 15 or a combiner according to Fig. 16, being coupled via optics in order to then connect the terminator to this single-mode fiber or other fiber.

However, it is also possible to unite the outputs of a plurality of fiber lasers or single-mode fibers or other suitable fibers into which laser radiation can be coupled via wavelength-dependent or polarized beam combiners or other suitable techniques, and to in turn couple into single-mode fibers or other fibers that can be provided with a respective, corresponding terminator at one or both ends.

The described possibilities of branching and uniting fibers can be particularly advantageously employed when the inventive modular structure is applied to the laser radiation source.

Fig. 17 shows the principle of an acousto-optical deflector. A piezo-electric transducer 45 is applied on a substrate 161 that is also referred to as crystal, said piezo-electric transducer 45 being supplied with electrical energy from a high-frequency source 162. The laser beam 163 incident at a Bragg angle α_B is deflected out of its direction proportionably to the frequency of the high-frequency source by interaction with the ultrasound field 164 within the crystal. When the beam that is not deflected and that passes through the modulator in a straight line is referenced I_0 (beam of the zero order), then the frequency f_1 yields

a direction I_{11} (first beam of the first order), and the frequency f_2 yields a direction I_{12} (second beam of the first order). Both frequencies can also be simultaneously present and the beams I_{11} and I_{12} arise simultaneously, these being capable of being modulated by varying the amplitudes of the high-frequency sources. An optimum transmission efficiency for the infed radiation respectively derives when the Bragg angle amounts to half the angle between the direction of the beam bundle I_0 and the direction of the deflected beam bundle. For use as acousto-optical modulator, only one of the sub-beams is used. It is mostly effective for processing materials to employ the beam of the zero order because it has the higher power. However, it is also possible to use one or more beams of the first order. The energy of the beams that is not used is neutralized in that, for example, it is converted into heat on a cooling surface. Only one piezo-electric transducer 45 is provided in Fig. 17, for which reason only one laser beam 163 can be deflected or modulated. However, a plurality of piezo-electric transducers can also be attached on the same substrate in order to thus simultaneously provide a plurality of laser beams, i.e. a plurality of channels, with different deflection or modulation signals. The individual channels are referenced T_1 through T_n. When, as shown in Fig. 17, the acousto-optical modulator is placed into a focal point of the lens 165 and the beam path is implemented nearly parallel through the acousto-optical modulator, the beams in the other focal point of the lens 165 are focused on the processing surface arranged here, and the beam axes between the lens 165 and the processing surface 81 proceed parallel and impinge the processing surface perpendicularly. Such an arrangement is called telecentric; the advantage is that the spacing between the beam axes remains constant when the position of the processing surface changes. This is of great significance for a precise processing of material.

Fig. 18 shows how the unused beam is neutralized. The unused beam is intercepted and deflected via a highly reflective mirror 166, which is preferably manufactured of metal for better heat elimination, is dispersed by a concave lens 75 and is directed onto an obliquely arranged plate 86 having bores 87 such that

no energy can be reflected back into the laser. The plate 86 and, potentially, the mirror 166 are also cooled via a cooling system that is operated by a pump 167. It is also possible to utilize a convex lens on a glass plate instead of the concave lens. The convex lens, particularly when a dispersion of the beam bundle to be neutralized can be undertaken with other techniques, which can occur, for example, by special shaping of the highly reflective mirror 166, is described under Fig. 4c. The concave lens 75 can also be omitted when one foregoes the advantage of the complete sealing of the laser gun. The plate 86 is shown with a planar surface at an angle. A plate having an arc or a cavity can also be employed. The surface can be roughened in order to absorb the laser energy well which is conducted to the coolant.

It is advantageous for an arrangement having a plurality of tracks to arrange a plurality of such modulators on a common crystal 34 according to Figs. 19 and 19a. The individual modulators cannot be arranged arbitrarily close to one another because of too much heating. A modulator of Crystal Technology Incorporated, Palo Alto, USA, is especially suited for the inventive arrangement, this being distributed under the designation MC 80 and containing five separate deflection or modulator channels. In this case, the spacing of the channels is predetermined at 2.5 mm, whereby the beam diameter is recited as 0.6 mm through 0.8 mm. A similar product by the same company is equipped with ten channels having a spacing of 2.5 mm. The spacing of the channels of 2.5 mm requires the diameter or the edge length of the terminators 26, 94 is implemented smaller than 2.5 mm. When the terminator 26, 94, however, is greater in diameter or in edge length than the spacing of the channels in acousto-optical deflector or modulator, an adaptation can be undertaken with an intermediate imaging, as shown in Fig. 25. Such a multi-channel deflector or modulator can also be employed in the exemplary embodiments according to Figs. 4, 4a, 4b, 4c, 36, 36a and 37. Dependent on the requirement of the application, all channels need not be used. Only four channels are shown in the illustrated applied examples.

Instead of the acousto-optical modulator, however, it is also possible to utilize other modulators, for example what are referred to as electro-optical modulators. Electro-optical modulators are described under the terms "laser modulators", "phase modulators" and "Pockels cells" on pages F16 through F33 of the overall catalog G3, Order No. 650020 of Laser Spindler & Hoyer, Göttingen. Multi-channel electro-optical modulators have also been possibly employed, which is shown in the publication "Der Laser in der Druckindustries" by Werner Hülsbuch, Verlag W. Hülsbusch, Constance, page 523, Fig. 8-90a. When a one-channel or multi-channel electro-optical modulator is employed in combination with a birefringent material, then each laser beam can be split into two beams that can be separately modulated via further modulators. Such an arrangement is also referred to as an electro-optical deflector in the literature.

Fig. 18a shows an arrangement having an electro-optical modulator 168. In an electro-optical modulator, for example, the polarization direction of the laser radiation that is not wanted for processing is separated from the incident beam bundle 163, and turned (P_b), and subsequently, the laser radiation P_b not wanted for the processing is separated off in a polarization-dependent beam splitter, which is also referred to as polarization-dependent mirror 169, and is conducted into a sump, for example into a heat exchanger that can be composed of a cooled plate 86. The radiation P_a wanted for processing is not turned in terms of polarization direction and is supplied to the processing surface via the lens 165. In the exemplary embodiments according to Figs. 4, 4b and 4c, the single-channel or multi-channel acousto-optical modulators 34 can be replaced by corresponding, single-channel or multi-channel electro-optical modulators. In the exemplary embodiments according to Figs. 4, 4b and 4c, the highly reflective mirror 74, 97 can likewise be replaced by the polarization-dependent mirror 169 (Fig. 18a), wherefrom an intercept arrangement 78 derives, and whereby the polarization-dependent mirror extends into the beam path desired for the processing.

The fiber laser can also be directly modulated. Such directly modulatable fiber lasers that have a separate modulation input available to them are offered,

for example, by IPG Laser GmbH D-57299 Burbach, under the designation "Modell YLPM Series". The advantage is that the acousto-optical modulators and the corresponding electronics for the high-frequency sources can be omitted. Moreover, the transmission unit can be simplified, as shown in Fig. 23.

Fig. 19 shows a plan view onto an acousto-optical deflector or modulator. It is mentioned in the description of Figs. 4, 4b and 4c that the space 44 or 111 according to Figs. 4, 4b and 4c wherein the modulators are arranged should be optimally free of those components that give off particles or gases because particles could thus settle onto the highly stressed optical surfaces, which would lead to the premature failure of the arrangement. For this reason, the electrical components of the arrangement in Figs. 19 and 19a are arranged on a separate printed circuit board 171 that merely has two arms projecting into the sealed space and produces the electrical connections to the piezo-electrical transducers 45. The printed circuit board 171 is sealed relative to the modulator housing 172, preferably with a solder location 173. The end face of the printed circuit board is preferably sealed by a metal band (not shown) that is soldered on in the region of the space 44 or 111. The printed circuit board is implemented in multi-layer fashion in order to shield the individual high-frequency channels by interposed connections to ground. Instead of a printed circuit board, some other line arrangement can also be utilized. For example, each radio frequency channel can be connected by its own shielded line. The modulator housing 172 contains an access opening 174 to the electrical components. The modulator crystal 34 can be metallized at its base area and is preferably secured on the modulator housing with a solder point or a glued connection 175. A connection 176 to a cooling system can be located directly under the fastening location in order to carry the waste heat off via the openings 87 with a coolant. The modulator housing 172 is preferably closed by a cover 177 that carries the electrical terminals 181 and also contains the connections for the cooling system, but this is not shown. A seal 43 sees to it that the modulator housing 172 is inserted gas-tight into the housing 35 or 93 of Figs. 4, 4a, 4b and 4c and is secured with the connection 42.

It is possible to secure the electro-optical modulator 168 to the modulator housing (172) in a similar way and to contact it via the printed circuit board 171.

Fig. 20 indicates that the basic beam path for the exemplary embodiment of Fig. 4 for the beam bundles 144 of the corresponding fiber lasers F_{HD1} through F_{HD4}. The beams bundles of the fiber lasers F_{VD1} through F_{VD4} proceed partially congruently with the indicated rays but, inventively, have a different wavelength and, as can be seen from Fig. 4a, are united via a wavelength-dependent mirror 37 (not shown in Fig. 20) with the beam packet F_{HD1} through F_{HD4} to form the beam packet F_{D1} through F_{D4}. Further, Fig. 20 does not show the beam packets of the fiber lasers F_{VR1} through F_{VR4} and F_{HR1} through F_{HR4} that, as can be seen from Fig. 4a, are likewise combined via a wavelength-dependent mirror to form the beam packet F_{R1} through F_{R4}. As can be seen from the arrangement of the strip mirror 46 in Fig. 4a, the beam bundles of the beam packet F_{R1} through F_{R4} in Fig. 20 would proceed offset by half a track spacing from the indicated rays. Instead of containing the indicated four beam bundles, thus the complete beam path contains a total of eight beam bundles that yield a total of eight separate tracks on the processing surface. Fig. 20 only shows the two beam bundles 144 of the fiber lasers F F_{HD1} and F_{HD4}. As already mentioned under Fig. 4, however, a plurality of tracks can also be arranged; for example, the plurality of tracks on the processing surface can also be increased to sixteen separately modulatable tracks. On the basis of a digital modulation of the respective laser, i.e. the laser is operated in only two conditions as a result of turn-on and turn-off, this arrangement enables an especially simple control and a good shaping of the processing spot on the processing surface. This digital type of modulation requires only an especially simple modulation system.

A distinction between more than 100 tonal value levels is required in high-grade multi-color printing in order to obtain adequately smooth color progressions; more than 400 tonal value stages would be optimum. When, for example, a cup in rotogravure wherein the volume of the cups determines the amount of ink applied onto the material being printed is composed of 8 x 8 or 16

x 16 small individual cups and the cup depth is kept constant, the processed surface can be quantitized into 64 or 256 stages. When, however, the cup depth is controlled by additional, analog or digital amplitude modulation or by a pulse-duration modulation of the laser energy, the volume of the cups can be arbitrarily finely quantized even given a low plurality of tracks. If, for example, the cup depth were digitally controlled in only two stages, as described in greater detail under Fig. 28, a cup could be composed of 8 x 8 individual cups given eight tracks, these potentially having respectively two different depths. For example, the volume of the cups in this case could be quantized in 128 stages without losing the advantage of purely digital modulation, which yields a considerable advantage for the stability of the method. Given 16 tracks and 2 stages in the cup depth, the number of digitally possible quantization stages already amounts to 512. It is also possible to generate the cups in two processing passes in order to increase the number of tonal value steps.

The modulators 34 as well as the strip mirror 46 are not shown in Fig. 20. For a better illustration, the cross-section of the beam bundle 144 from the terminator of the fiber laser F_{HD1} that is congruent with the ray beam F_{D1} after passing the wavelength-dependent mirror is designed with a hatching. Like all other illustrations, this illustration is not to scale. The two illustrated beam bundles 144 yield the processing points B_1 and B_4 on the processing surface 81 that contribute to the built-up of the processing spot 24 and generate corresponding processing tracks on the processing surface 81. The axes of the terminators 26 and of the beam bundles 144 of the individual fiber lasers proceed parallel to one another in Fig. 20. The beam cones of the terminators, i.e. the shape of the ray beam 144, are shown slightly divergent. In the Figure, a beam narrowing within the lens 133 is assumed in the Figure. The divergence angle is inversely proportional to the diameter of the beam bundle in the corresponding beam narrowing. The position of the beam narrowing and its diameter, however, can be influenced by varying the lens 133 in the terminator 26, 94 and/or its distance from the fiber 28 or from the laser fiber 5. The calculation of the beam

path occurs in the known way. See the technical explanations on pages K16 and K17 of the general catalog G3, Order No. 650020 of Laser Spindler & Hoyer, Göttingen. The objective is that the processing points B_1 through B_n of the processing surface 81 respectively become beam narrowings in order to obtain the highest power density in the processing points. With the assistance of the two lenses 55 and 56, beam narrowings and track spacings from the object plane 182 wherein the lenses 133 of the terminators 26 lie are imaged in demagnified fashion in an intermediate image plane 183 corresponding to the ratio of the focal lengths of the lenses 55 and 56. When, in this case, the distance of the lens 55 from the terminator 26 and from the crossing point 184 is equal to its focal length and when the distance of the lens 56 from the intermediate image plane 183 is equal to its focal length and equal to its spacing from the crossing point 184, what is referred to as a telecentric imaging is obtained, i.e. the axes of the beam bundles belonging to the individual tracks begin to proceed parallel in the intermediate image plane. The divergence, however, has been noticeably increased. The preferably telecentric imaging has the advantage that the diameters of the following lenses 57 and 61 need only be insignificantly larger than the diameter of a beam bundle. The lenses 57 and 61 demagnify the image from the intermediate image plane 183 in a second stage onto the processing surface 81 in the described way. A preferably telecentric imaging, namely that the axes of the individual beam bundles proceed parallel between the objective lens 61 and the processing surface 81, has the advantage here that changes in spacing between the processing surface and the laser gun produce no change in the track spacing, which is very important for a precise processing. The imaging need not necessarily occur in two stages with two lenses each; there are other arrangements that can also generate parallel beam axes between objective lens and processing surface, as shown in Figures 21 and 22. Deviations in the parallelism of the beam axes between the objective lens 61 and the processing surface 81 can also be tolerated as long as the result of the processing of the material is satisfactory.

Fig. 21 shows a fundamental beam path for the exemplary embodiment of Fig. 4b. The illustration is not to scale. As was already the case in Fig. 20, the two beam bundles 144 of the lasers F_{HD1} and F_{HD4} are only a matter of a sub-set of the beam bundles of all existing lasers in order to explain the principle. In contrast to Fig. 20, however, the axes of the individual beam bundles of the terminators in Fig. 21 are not parallel but are arranged at an angle relative to one another, which is shown in greater detail in Fig. 24, and which is advantageously achieved by terminators 94 according to Figs. 10, 10a and 10b. As a result of this arrangement, the individual beam bundles 144 would cross similar to the case in Fig. 20 without a lens 55 being required. In the region of the imaginary crossing point, the dispersive lens with a short focal length, i.e. a concave lens 101 is inserted, this bending of the incoming rays off and rendering of the beam bundles divergent is shown, i.e. widening them. The convex lens 102 is preferably arranged in the intersection of the axial rays and, together with the lens 101, forms an inverted Galileo telescope. As a result thereof, for example, parallel input beam bundles are converted into parallel output beam bundles having an enlarged diameter between the lenses 102 and 103. The desired parallelism of each input beam bundle can, as already described, be undertaken by a suitable selection of focal length and spacing of the lens 133 from the fiber 28 or laser fiber 5 in the terminators 26, 94. The objective lens 103 focuses the enlarged beam bundle onto the processing surface 81 at the processing points B_1 through B_4 that contribute to the build-up of the processing spot 24 and generate corresponding processing tracks on the processing surface 81. The imaging scale can be modified in a simple way by modifying the focal length of the lens 103. It is therefore advantageous when the lens 103 is implemented as an interchangeable objective lens. As already described, however, a vario-focusing optics can also be employed. When the position of the lens 103 is selected such that the distance between the lenses 102 and 103 corresponds to the focal length of the lens 103, the axes of the beam bundles between the lens 103 and the processing surface are

parallel and yield constant spacings of the tracks of the processing surface, even given a modified distance between the laser gun and the processing surface.

Fig. 22 indicates the fundamental beam path for the exemplary embodiment of Fig. 4c. Like all other figures, the illustration is not to scale. The beam path is very similar to that of Fig. 21, with the difference that an arced mirror 121 is employed instead of the lens 101 and a concave mirror 115 is employed instead of the lens 102. The beam path is considerably shorter due to the folding that derives. The beam path approximately corresponds to that of an inverted mirror telescope. Mirror telescopes are independent of the wavelength which is advantageous given employment of lasers having different wavelength. The imaging errors can be reduced by employing aspherical surfaces or with an optical correction plate 117 that, however, is not shown in Fig. 22. It is advantageous when the focal length of the objective lens 112 is equal to its spacing from the concave mirror. The axes of the ray bundles are then parallel between the lens 112 and the processing surface 81 and yield constant spacings of the tracks on the processing surface, even given a modified distance between the laser gun and the processing surface. Moreover, an advantageously large spacing of the objective lens from the processing surface derives. As described a vario-focusing optics can also be utilized.

Fig. 23 shows an arrangement having a plurality of lasers, whereby the individual laser outputs in the form of the terminators 26 are arranged on a circular segment and aim at a common cross-over point 185. This arrangement is particularly suitable for directly modulatable lasers since a very low expense then results. In such an arrangement, the imaging on the processing surface 81 can occur with only a single lens 186. However, an arrangement according to Figs. 4b or 4c can also be employed for imaging. The ray cones of the beam bundles from the terminators are set such that a beam narrowing and, thus, a sharp image derives for all lasers on the processing surface 81. Preferably, the spacings between the cross-over point 185 and the lens 186 as well as between the lens 186 and the processing surface 81 are of the same size and correspond to the focal

length of the lens 186. In this case, the axes of the individual ray bundles between the lens 186 and the processing surface 81 are parallel and yield constant spacings between the processing tracks, even given a modified distance between the laser gun and the processing surface. Although not shown, a plurality of levels of lasers can also be arranged above one another in order to increase the power density and the power of the laser radiation source. The planes of the lasers are preferably arranged parallel to one another. As shown in Figs. 29 and 31, it then derives that the individual ray bundles from the individual planes meet on a spot in the processing points on the processing surface 81 and thus generate an especially high power density.

Fig. 24 shows a modification relating to Fig. 23. Four fiber lasers F_{HD1}, F_{HD2}, $F_{HD3,}$ F_{HD4} have their terminators 94, which are described in greater detail in Figs. 10, 10a and 10b, joined to one another on a circular segment. The terminators 94 are particularly suited for joining to one another as a result of their shape. Since no directly modulatable fiber lasers are employed here, a four-channel acousto-optical modulator 34 is inserted. The piezo-electric transducers 45 can, as shown in Fig. 24, likewise be arranged on a circular segment. As shown in Fig. 24a, however, they can also be arranged parallel as long as the ray bundles are still adequately acquired by the acoustic field of the piezo-electric transducers 45. Instead of the lens 186, a transmission unit as described in Figs. 4b and 4c is advantageously employed.

Fig. 25 indicates a demagnifiying intermediate imager with the lenses 191 and 192, so that the distance between the individual terminators 26, 94 can be greater than the distance between the individual modulator channels T1 through T4 on the multi-channel acousto-optical modulator 34. The imaging ratio corresponds to the relationship of the focal lengths of the two lenses 191 and 192. The intermediate image is preferably telecentrically designed in that the distance of the lens 191 from the lenses 133 of the terminators 26 or 94 and from the cross-over point 193 is equal to its focal length, and in that the distance from the crossing point 193 to the lens 192 as well as the distance of the lens 192 from the

modulator crystal 34 is equal to its focal length. By adjusting the distance between the two lenses, however, one can also achieve that the rays emerging from the lens 192 no longer proceed parallel but at an angle relative to one another in order to connect the beam path according to Figs. 21 or 22 thereto. An intermediate image according to Fig. 25 can also be employed in combination with an arrangement of the terminators on a circular segment according to Figs. 23 and 24.

The intermediate imager (191, 192) is shown in Fig. 25 between the terminators (26, 94) and the modulator (34). However, a wavelength-dependent or polarization-dependent mirror 37 can also be arranged preceding or following the intermediate imager in the beam direction. An intermediate imager (191, 192) can also be arranged in the beam path following the modulator, before or after the strip mirror 46. Preferably, the intermediate imager in the beam path is inserted at the locations referenced "E" in Fig. 4a.

Figs. 26 and 26a show how the distance between the tracks in the processing plane can be reduced. Fig. 26 is a side view and Fig. 26a is the appertaining plan view. Since the beam bundles 144 emerging from the terminators 26, 94 have a smaller diameter than the housing of the terminators, interspaces remain that are not utilized. Moreover, the minimum distances between the tracks and the maximum diameters of the beam bundles are prescribed by the multi-channel acoustic-optical modulators 34. In order to decrease the distances between the tracks, a strip mirror 46 is provided that is transparent and mirrored in alternating fashion in stripe-shaped fashion at intervals. The strip mirror 46 and the modulators are not shown in Fig. 26a. Such a strip mirror 46 is shown in Figures 27 and 27a, whereby Fig. 27a shows a side view of Fig. 27. Highly reflective strips 195 are applied on a suitable substrate 194 that is transparent for laser radiation. The interspaces 196 as well as the backside are preferably provided with a reflection-reducing layer. The beam bundles 144 from the terminators 26, 94 of the fiber lasers F_{D1} through F_{D4} pass unimpeded through the transparent part of the strip mirror 46. The beam bundles

144 from the terminators 26, 94 of the fiber lasers F_{R1} through F_{R4} are arranged such that they are reflected at the strips of the strip mirror such that that they lie in a row with the ray bundles F_{D1} through F_{D4}. The distance between the tracks has thus been cut in half.

Fig. 27b shows a strip mirror 46, whereby the substrate of the mirror was removed in the interspaces 196, and the entire, remaining surface is preferably highly reflectively mirrored, so that strips 195 derive. In this case, the strip mirrors can be preferably manufactured of metal, which is especially advantageous given high powers and the heating connected therewith.

An arrangement having strip mirrors can be combined very well with an arrangement having wavelength-dependent mirrors, as shown, for example, in Figures 4, 4a, 4b, 4c. The further beam path according to Fig. 20 can be connected via the lens 55. The axes of the individual terminators 26, 94, however, can also be arranged at an angle, as shown in Figs. 23 and 24. In this case, the further beam path can proceed according to Fig. 21 or 22 and the lens 55 is omitted.

Figs. 28 and 28a show how fiber lasers of different wavelength, for example Nd:YAG lasers having 1060 nm and those having a different doping with 1100 nm are combined with one another via a wavelength-dependent mirror 37. The wavelength difference can be less but can also be greater.

The modulators and the wavelength-dependent mirror are not shown in Fig. 28a. Preferably, wavelength-dependent mirrors are optical interference filters that are manufactured by vapor-deposition of suitable dielectric layers onto a substrate that is transparent for the appertaining wavelengths and can have very steep filter edges as high-pass or low-pass filters. Wavelengths up to the filter edge are allowed to pass; wavelengths beyond the filter edge are reflected. Band-pass filters are also possible. Likewise, lasers of the same wavelength but a different polarization direction can be combined via polarized beam combiners, preferably polarization prisms. Inventively, a combination of polarized beam combiners and wavelength-dependent mirrors is also possible. In Fig. 28, the

beam bundles 144 emerging from the terminators 26, 94 of the fiber lasers F_{HD1} through F_{HD4} with the wavelength λ_1, pass unimpeded through a wavelength-dependent mirror 37, whereas the beam bundles F_{VD1} through F_{VD4} having the wavelength λ_2 are reflected at it and, thus, the two beam bundles are united in one another following the mirror. Each beam bundle can be separately modulated according to the invention via a respective multi-channel, acousto-optical modulator 34. Since respectively two lasers of different wavelengths process the same track in the same processing point on the processing surface, a digital amplitude modulation in 2 stages is possible in a simple way in order, for example, to control the depth of the cups when producing printing forms for rotogravure when the two participating beam bundles are respectively merely turned on or off. However, a shared modulator for the two united beam bundles can also be employed. In this case, the modulator is arranged between the wavelength-dependent mirror 37 and the lens 55, as shown in Figs. 4, 4a, 4b, 4c. The further beam path of the transmission unit according to Fig. 20 connects via the lens 55. However, the axes of individual terminators 26, 94 can also be arranged at an angle relative to one another, as shown in Figs. 23 and 24. In this case, the further beam path can proceed according to Fig. 21 or 22 and the lens 55 can be omitted.

Fig. 29 shows how fiber lasers with their terminators 26, 94 (Fig. 31) can be arranged in a plurality of planes. Three planes of terminators that are connected to fiber lasers lie above one another. The first track is referenced F_1 for the first plane, with F_2 for the second plane and with F_3 for the third plane. The numerals 11, 12 and 13 reference the first plane of the further tracks. The axes of the beam bundles 144 emerging from the terminators are directed parallel to one another in the individual planes. The axes of the beam bundles of the individual tracks can proceed parallel to one another, as shown in Fig. 20, or at an angle relative to one another according to Fig. 23 or 24.

In Fig. 30, the terminators 26, 94 (Fig. 31) of, for example, seven fiber lasers F_1 through F_7 are arranged in a hexagon such that the axes of their ray

bundles 144 are parallel to one another. To this end, terminators according to Fig. 12 can be advantageously employed. As a result thereof, the smallest possible diameter of a common ray bundle composed of seven individual ray bundles derives.

First, Fig. 31 is first a sectional view through the three planes of the first track of Fig. 29. A lens 107 collects all incoming parallel rays in its focal point 201 on the processing surface 81. As a result thereof, power and power density are multiplied by the plurality of lasers united in the focal point, i.e. are tripled given three planes. When the axes of the beam bundles emerging from the terminators 26, 94 proceed parallel to one another for tracks and planes, the beam bundles of all tracks would likewise be additionally united in the focal point, and a common processing point would arise on the processing surface that generates a processing track. When the axes of the beam bundles emerging from the terminations 26 proceed under an angle as shown in Fig. 23 or 24, every track of termination will generate a processing point, which generates a processing track I.e., the same number of processing tracks are registered next to one another as there are tracks of terminators. The power of the beam beams of the various planes is superimposed in the respective processing point and the power density is tripled in the illustrated example. The individual fiber lasers can thereby be directly modulated; however, external modulators can also be employed. Figs. 32 and 33 describe how a multiple-channel acousto-optical modulator corresponding to the number of tracks can be preferably employed for the simultaneous modulation of all ray bundles of the various planes.

Fig. 31 is also a sectional view through the bundle arrangement according to Fig. 30. It is known that parallel ray bundles that are incident into a lens have a common focus. Page 13, Fig. 2.21 in the book "Optik und Atomphysik" by R. W. Pohl, 13th edition, 1976, Springer Verlag shows such an arrangement. Further, DE-A-196 03 111 discloses an arrangement wherein, as can be seen from Fig. 1 therein, the radiation from a plurality of laser diodes is respectively coupled into a single-mode fiber, the radiation at the output of each fiber is collimated to a

respective, parallel beam bundle, and all parallel beam bundles are directed onto a common spot with a shared lens in order to achieve an increased power density. Compared to the arrangement shown in Fig. 31 with fiber lasers, however, this arrangement has serious disadvantages. When radiation is to be efficiently coupled into single-mode fibers, single-mode laser diodes are required for this purpose so that the aperture of the single-mode fibers is not overfilled and the total radiation can be transmitted into the core of the single-mode fiber. Single-mode laser diodes, however, can only be manufactured with extremely limited power because the loadability of the minute laser mirrors represents a technological barrier. Single-mode laser diodes are therefore only available up to an output power of approximately 200 mW and are far more expensive per watt than multi-mode diodes that are offered with radiation powers of up to several kilowatts. Given single-mode fibers for 800 nm wavelength, the product of core diameter and numerical aperture amounts to approximately 5 μm x 0.11 = 0.55 μm, whereas this lies at 300 μm x 0.4 = 120 μm given a fiber laser having a typical diameter of the pump fiber of 300 μm and a numerical aperture of 0.4, which amounts to a factor of 220. When the area ratio of the two fibers is considered, then a factor of $(300/5)^2 = 3600$ derives. Even when a reduction of the laser radiation by the factor of the absorption efficiency of approximately 0.6 is assumed given the fiber laser, this being the efficiency with which the pump radiation is converted into laser radiation, the power of the laser radiation that can be achieved at the output of a fiber laser is several orders of magnitude higher than the power at the output of a single-mode fiber. Even if single-mode diodes or other laser radiation sources having very high power were available, it would nonetheless not be possible to couple this satisfactorily into single-mode fibers, since the fibers would burn given the slightest misadjustment at the fiber entry. This problem does not exist given fiber lasers since a relatively large fiber diameter is available for the pumping and the energy is transmitted into the single-mode core of the laser fibers only within the laser fiber, which is possible unproblemmatically and with good efficiency.

The lens 197 in Fig. 31 unites the entire power of all seven beam bundles F_1 through F_7 of the corresponding fiber lasers in its focal point 201 which represents the processing spot 24 on the processing surface 81. The power and the power density in the focal point thus become higher by the factor of 7 than is the case given an individual beam bundle. When, for example, 100 W are required in order to generate a required power density on the processing surface, then seven lasers having a radiant power of approximately 15 watts each suffice in this case. However, more than seven lasers can be provided. The lasers can preferably be directly modulated. However, it is also possible to modulate all seven beam bundles separately or overall with an external modulator or to supply a plurality of such bundle arrangements to a multi-channel modulator in such a way that the modulator channels are preferably arranged in the focal point of a uniting lens 197 that is allocated to each bundle. It is also possible to couple the multiplied power of each and every bundle into fibers before or after the modulation. Further, such bundle arrangements can be advantageously utilized in laser guns according to Figs. 4, 4a, 4b, 4c.

It is advantageous to separately modulate the individual lasers. This is especially suitable when a high number of lasers is employed, since, for example, a quantized modulation that is similar to an analog modulation, a quasi-analog modulation of the united laser radiation is then enabled by digital modulation of the individual lasers. However, it is also possible to modulate the beam bundles 144 of all lasers in common, for example with an acousto-optical modulator. In this case, the ultrasound field of the modulator cell must exhibit such a size that the overall beam bundle shown in Fig. 30 can be modulated. However, the switching time of the acousto-optical modulator becomes so great as a result thereof that the shape of the cups to be engraved is disturbed as a consequence of the rotational movement of the drum containing the processing surface. However, it is possible to entrain the laser beam with a deflection motion in the direction of the rotary motion of the printing cylinder to be engraved during the engraving and to thereby achieve a processing spot 24 that is stationary on the processing

surface. Inventively, the deflection motion can occur with the same acousto-optical modulator with which the amplitude modulation occurs. However, another acousto-optical cell can also be utilized, the deflection occurring therewith.

Fig. 32, in a farther-reaching example, shows how the power density on the processing surface can be considerably increased by providing terminators 26, 94 with the corresponding fiber lasers in a plurality of planes, but a modulation of all beam bundles 144 belonging to a track can be simultaneously implemented with a single-multi-channel, acousto-optical modulator 34 corresponding to the plurality of tracks. In this example, the terminators are arranged in three planes of n tracks each that lie above one another. The power of all ray bundles 144 of all planes should be largely focused in a processing point in the processing surface for each track in order to achieve a high power density. The terminators 26, 94 are arranged parallel to one another in tracks and planes, since the terminators 26 are joined to one another in close proximity. As shown, terminators having a round cross-section can be employed for this purpose; preferably, however, terminators having a quadratic cross-section according to Figs. 9 and 9a are utilized. Given the parallel arrangement of the tracks, the illustrated imaging system having the cylindrical lenses 202 and 203, also refer to as cylinder optics, can, for example, be added analogous to an arrangement like that of Fig. 4. When the individual tracks are to proceed at an angle according to Figs. 23 or 24, terminators 94 according to Figs. 10, 10a and 10b are preferably employed. In this arrangement, too, the beam bundles of the individual planes remain parallel; the fits of the terminators 94 should proceed parallel in the side view of Fig. 10a for this purpose. When the axes of the ray bundles for the tracks proceed at an angle relative to one another, the cylinder optics having the lenses 202 and 203 can be added, for example analogous to the arrangements according to Figs. 4b or 4c. The beam bundles 144 emerging from the terminators are directed onto the convex cylinder lens 202 that would combine the rays in its focus to form a line having the length of the beam diameter. A concave cylinder lens 203 having a

shorter focal length then the cylinder lens 202 is attached such in the region of the focus of the cylinder lens 202, 203 having a long focal length such that its focus coincides with the focus of the cylinder lens 202. As a result thereof, the rays that leave the lens 203 become parallel again. The spacings between the individual planes, however, have been reduced by the ratio of the focal lengths of the two cylinder lenses compared to the spacings that the beam bundles had when they left the terminators 26, 94. The spacings of the beam bundles have remained unmodified in the direction of the tracks since the cylinder lenses exhibit no refractive effect in this direction. As a result thereof, elliptical beam cross-sections derive in the modulator. The purpose of this arrangement is to make the overall height of the three ellipses lying above one another so small that it approximately corresponds to the major axis of the ellipses in order to create conditions in the channels of the acousto-optical modulator similar to those achieved given a round beam cross-section so that, for example, similarly short switching times can be achieved.

Fig. 33 shows that, however, the spacing of the two cylinder lenses can also be modified somewhat so that all three elliptical beam bundles overlap in the modulator, this is in fact yielding a shorter switching time in the acousto-optical modulator but also yielding an increased power density in the modulator crystal. The cylinder lens 203 can also be omitted for this purpose.

The cylinder optics (202, 203) is shown in Fig. 25 between the terminators (26, 94) and the modulator 3. However, a wavelength-dependent or polarization-dependent mirror 37 can also be arranged preceding or following the cylinder optics in beam direction. A cylinder optics (202, 203) can also be introduced in the beam path following the modulator, preceding or following the strip mirror 46. Preferably, the intermediate image is inserted in the beam path at the locations references "E" in Fig. 4a.

For removing the material eroded from the processing surface, Fig. 34 shows a mouthpiece 82 whose main job is to use a directed flow to take care that optimally no clouds of gases and/or eroded material form in the optical beam path

between objective lens and processing surface 81, these clouds absorbing a part of the laser energy and depositing on the processing surface and thus negatively influencing the work result.

As a result of its specific shaping, the mouthpiece 82 prevents the described disadvantages. Preferably, it is secured to the laser gun with connections 204 that are simple to release, so that it can be removed and cleaned in a simple way and also enables a simple cleaning as well as a simple replacement of the objective lens (not shown) 61, 103, 112. A cylindrical bore 206 for adaptation to the objective lens and a preferably conical bore 207 as passage for the beam bundle as well as another preferably cylindrical bore that represents the processing space 211 are located in a preferably cylindrical base member 205. The distance of the base member 205 from the processing surface 81 should not be excessively great. The processing points (not shown) for producing the individual processing tracks on the material to be processed lie in the processing spot 24. A broad, all around extraction channel 212 is preferably located in the base member, this channel 212 being connected to the processing space 211 via a plurality of extraction channels 213 that should have a large cross-section. Preferably, 3 through 6 extraction channels 213 are present. A further, preferably all around admission channel 214 is located in the base member, this channel 214 being connected via nozzle bores 215 to the processing space 211 and to the conical bore 207 via smaller bypass bores 216. 3 to 6 nozzle bores 215 and 3 to 20 bypass bores 216 are preferably distributed over the circumference of the admission channel 214. All bores can be offset relative to one another and relative to the extraction channels 213 on the circumference. Further bypass bores can also be attached and directed onto the objective lens. This, however, is not shown. The base member is surrounded by a ring 217 applied gas-tight that contains a plurality of extraction connectors 221 in the region of the channel 212 to which extraction hoses are connected, these being conducted via an extraction filter to a vacuum pump. The extraction hoses, the extraction filter and the vacuum pump are not shown in Fig. 34. In the region of the channel 214, the ring

contains at least one admission connector 222 via which compressed air filtered with an admission hose is supplied. The quantity of admitted air can be set with a valve such that it is just adequate in order to adequately rinse the processing space and such that it generates a slight air stream along the conical bore via the bypass bores that largely prevents a penetration of particles into the conical bore. The admission hose, the valve and the filter are not shown in Fig.3 4. The nozzle bores 215 are directed such onto the processing spot 24 such that the clouds of gas, solid and molten material arising in the processing are quickly blown out of the beam path so that these absorb as little laser energy as possible and cannot negatively influence the processing result. Oxidation-promoting or oxidation-inhibiting gases or other gases can also be blown in with the admission air, these having a positive influence on the processing process. A slight quantity of air from the environment co-flows through the processing space to the extraction channels through the gap between the processing surface and the base member 205; this, however, is not shown. The filter in the extraction line is attached easily accessible in the proximity of the mouthpiece and sees to keeping the vacuum pump clean. It is also possible to introduce the filter directly in the extraction channel 212. As described under Fig. 39a, it is useful when a protective atmosphere is additionally conducted over the objective lens. If the mouthpiece 82 becomes too hot due to the laser radiation reflected from the processing surface and the air that flows through does not suffice for cooling, then the mouthpiece can be provided with additional bores through which a coolant is pumped; this, however, is not shown in the Figs. A glass plate 218 that is highly anti-reflection coated on both sides and is simple to change can also be located within the cylindrical bore 205, this glass plate 218 keeping dirt particles away from the objective lens. The shape of the mouthpiece can also deviate from the form that is described and shown. For example, the bores need not be cylindrically or conically implemented, as described; they can be varied in shape. Likewise, for example, the nozzle bores and extraction channels can assume arbitrary shapes and can also be asymmetrically arranged. For example, the

nozzle bores in Fig. 34 can be arranged more in the upper part of the Fig., whereas the extraction channels lie more in the lower part of the Figure. For example, the nozzle bores and/or the bypass bores can also be foregone. The shape of the mouthpiece can also be modified, particularly when the shape of the processing surface and the type of relative motion between processing surface and laser radiation source demand this. It is conceivable to utilize a modified form of the described mouthpiece when the material to be processed is located, for example, on a planar surface instead of on a drum surface, and the laser radiation is conducted past this line-by-line. In this case referred to as flatbed arrangement, which is shown in greater detail in Figures 43, 43a and 43b, the mouthpiece is implemented elongated corresponding to the line length and is provided with an elongated processing space corresponding to its length. The mouthpiece is equipped with nozzle bores and extraction channels from one or from both sides. In this case, the glass plate would be given a rectangular shape and would extend over the entire length of the arrangement. In this case, Figure 34 could be analogously considered as a cross-section of the elongated mouthpiece. Even when the material to be processed is located in a hollow cylinder, which is not shown in detail in Figs 44a and 44b, a similar mouthpiece can be produced in that the mouthpiece described for the flatbed arrangement is adapted in the longitudinal direction to the shape of the hollow cylinder such that a slight gap between the processing surface and the mouthpiece derives over the entire length. The glass plate would be given a rectangular shape in this case and would be curved over the entire length of the arrangement.

A generally known scraper device that, however, is not shown in the figures can be located in the proximity of the mouthpiece but need not necessarily be connected to it or to the laser gun. For example, the job of the scraper device is to scrape off the ejects arising at the edges of the cups during the processing process at rotogravure forms. Further, a brush device (not shown) can preferably be located in the proximity of the laser gun, this brushing out the cups that have been cut and ridding them of adhering dirt. Further, a measuring device (not

shown) can be preferably inventively located at the laser gun, this measuring the position and/or the volume of the cups immediately after they are produced. In contrast to cups that have been manufactured by electro-mechanical engraving or with a single laser beam, the volume can be inventively more precisely identified for cups that are produced with the inventive laser radiation source and have steep edges and constant depth, in that the area of the cup is determined with a specific, fast camera and the volume is derived therefrom. It is thereby advantageous to measure a series of cups in order to reduce measuring errors. It lies within the framework of the invention that specific control fields are engraved in a region of the rotogravure cylinder, this being provided for monitoring measurements and/or for monitoring prints. A rated/actual comparison can be produced with this measured quantity for the generated cups and with the cup size prescribed for this location. The result can then be employed in order to correct the position and/or the volume of the subsequently produced cups.

Fig. 35 shows the conditions on the processing surface. The processing points are identified with the indices that indicate the ray bundles of the fiber lasers according to Figs. 4, 4a, 4b and 4c that produce them. For example, the ray bundles of the fiber lasers F_{VR1} and F_{HR1} generate the processing point $B_{FVR1+FHR1}$ in common to the diameter of the processing points is referenced B, and their spacing is referenced A. In the multi-channel, acousto-optical modulator described under Figs. 19 and 19a, the allowable diameter of the beam bundle 144 is smaller than the spacing of the channels of the modulator. The diameter of the ray bundle 144 in the terminators 26, 94 cannot be made just as large as the outside diameter of the terminators without great expense. It follows therefrom that A is thus greater than B. This leads to undesired interspaces at the processing tracks 224 that derive as a result of the relative motion between the material to be processed and the laser gun. The processing tracks have a track width D that corresponds with the diameter of the processing points B and are referenced as 1 through 8 in Fig. 35. In order to reduce these interspaces, two beam packets were already nested inside one another with the strip mirror, as described under Figs. 4,

4a, 26 and 26a, in order to cut the interspaces in half. In order to reduce the remaining interspaces even more, or to entirely avoid them or cause the processing tracks 224 to overlap, the laser gun can be turned such compared to the relative motion direction between the material to be processed and the laser gun such that the tracks come closer to one another, this being shown in Fig. 35. In order, for example, to achieve a spacing C of the processing tracks 224 that is equal to the diameter B of the processing points, the laser gun must be turned by the angle β according to the relationship $\cos \beta = B/A$. Distortions in the image information arise on the processing surface due to the rotation of the laser gun, since the starts in the individual processing tracks are now shifted relative to one another. These distortions, however, are already compensated in the editing of the processing data. It is also possible to undertake this compensation by an adjustable, different delay of the signals in the individual data channels immediately before the modulation or to simply accept the distortions. Further possibilities for setting and reducing the spacings of the processing tracks are presented in Figs.36, 36a, 36b, 36c and 37.

Fig. 36 shows the principle of how processing points $B_1 \ldots B_4$ derive on the processing surface 81 when the individual channels are charged with different frequencies f_1 through f_4 in a multi-channel acousto-optical modulator 34 having four separate channels. For example, the modulator channel T_1 (Fig. 36a) is thereby supplied with a frequency f_1, whereby f_1 is provided with a higher frequency compared to f_4 in the modulator channel T_4 (Fig. 36a), so that a greater spacing of I_0 derives for the processing track 1 than for the processing track 4. The channels T_2 and T_3 are provided with corresponding frequencies f_2 and f_3 in order to achieve the illustrated arrangement of the processing tracks 224. However, the frequencies can also be arranged such that the frequency f_1 is lower then the frequency f_4. It is also possible to arbitrarily allocate the frequencies f_1 through f_4 to the individual modulator channels T_1 through T_4. In this case, a lens 165 as shown in Fig. 17 and Fig. 36a is not absolutely necessary; rather, the laser

radiation emerging from the terminators can be focused such that a sharp image derives in the processing points on the processing surface.

How the beam bundles focused by the lens 165 impinge the generated line M of the drum is shown in Fig. 36a with reference to an example (not to scale) with the rotating drum on which the processing surface 81 lies. The position of the puncture points P of the ray axes with the plane of the lens 165 thereby corresponds to the principle of Fig. 36. For that purpose, the modulator 34 with the channels T_1 through T_4 is correspondingly arranged relative to the beam bundles 144 of the fiber lasers F_1 through F_4. What is achieved by a suitable selection of the frequencies f_1 through f_4 is that the partial rays that generate the processing points B_1 through B_4 lie at desired distances from one another in the direction of the generated line M. This has the advantage that the position of each processing point and, thus, of each processing track 224 can be individually set by adjusting the corresponding frequency. A particular advantage of the arrangement derives when, as indicated in Fig. 17, the multi-channel acousto-optical modulator is arranged approximately in the one and the processing surface is arranged approximately in the other focal point of the lens 165, and the axes of the beam bundles of the fiber lasers F_1 through F_4 are arranged approximately in parallel planes. The processing points B_1 through B_4 then lie in a row on the generated line M (Fig. 36a), and the axes of the partial rays that form the processing points are parallel and reside perpendicularly on the processing surface (Fig. 17). Another advantage of the arrangement is that the Bragg angle for optimizing the efficiency can be individually set for each modulator channel, but this is not shown in the Figures. In this example, the deflected rays are used for processing material, whereas the non-deflected rays I_0 are blanked out by an intercept arrangement similar to that shown in Figure 18. In contrast to the arrangement in Figure 18, it is shown here that the mirror 166 acting as intercept arrangement can also be arranged between the lens 165 and the processing surface. As described under Fig. 4, however, the intercept arrangement can also be foregone when a symmetrical or asymmetrical defocussing reduces the radiation that is contained

in I_0 and is unwanted for processing in terms of its power density to such an extent that no processing effect is produced when it is directed onto the processing surface.

Fig. 36b shows an expanded embodiment of Fig. 36a in a side view. The lenses 202 and 203 are inserted between the multi-channel modulator with the channels T_1 through T_n, said lenses 202 and 203 being preferably cylinder lenses and forming a cylinder optics, as described under Fig. 32 and Fig. 33. This cylinder optics demagnifies the distance between the channels T_1 and T_n at the location of the lens 166 and, given a predetermined focal length of the lens 165, thus, the angle at which the rays of the individual channels T_1 through T_n impinge the processing surface, is particularly significant given a great number of channels and significantly favors the costs for the lens 165, which can also be a system composed of a plurality of lenses, as well as its makeability.

Fig. 36c shows a plan view relating to Fig. 36b, from which it can be seen that the cylinder optics exhibits essentially no effect in this view. The ray bundles F_1 through F_n coupled into the acousto-optical modulator 161 are in fact shown under the same Bragg angle; however, they can also, however, be coupled in individually differently under the respectively optimum Bragg angle.

Fig. 37 emphasizes another advantage of the arrangements according to Figs. 36, 36a, 36b and 36c, namely that respectively two processing points B_{11}, B_{12} through B_{41}, B_{42} can now be generated instead of the processing points B_1 through B_4 by simultaneous application of two different frequencies to the respective modulator channels. Instead of four processing tracks, eight separately modulatable processing tracks 224 have now arisen without increasing the number of lasers and/or the number of modulator channels. It lies within the scope of the invention to also employ more than two frequencies per modulator. Twelve different frequencies with a single modulator channel have already been realized for a similar purpose. Another advantage in the generation of processing points with acousto-optical deflection is the possible shift of the processing points at high deflection speed. By modifying the applied frequencies, individual or all

processing tracks 224 can be very quickly displaced relative to their previous position and there is thus a further possibility of beneficially influencing the position and shape of the cups. With this technique, in particular, the position of the processing tracks can be correspondingly readjusted to a rated quantity with high precision. Precisions of a fraction of a track width are thereby possible. Inventively, the actual position of the individual processing tracks can be precisely determined with a known, interferometrically functioning measuring system in that, for example, the actual position of the laser radiation source is registered during the processing event and a correction signal for the required displacement and readjustment of the processing tracks is generated by comparison to the rated position of the processing tracks. This can be of interest particularly when a seamless joint is to be made to a processing pattern that already exists or when a pattern that already exists is to be post-processed. Another enormous advantage of the arrangement is that the Bragg angle can be individually set for optimizing the efficiency for each modulator channel, which, however, is not shown in the Figures. Up to now, acousto-optical arrangements wherein a plurality of sub-beams are generated from a laser beam by applying a plurality of frequencies wherein all of these have a shared Bragg angle for all sub-beams, has not yet made a breakthrough in processing of materials because the efficiency is too low. When, however, a combination of a number of laser beams having respectively individually set Bragg angle and a number of acousto-optically generated sub-beams per laser beam is selected as proposed, then a clearly higher efficiency can be achieved, so that a great plurality of simultaneously acting processing tracks can be realized for processing material.

As described under Figs. 18 and 18a, however, single-channel or multi-channel electro-optical modulators can also be utilized in conjunction with a birefringent material in order to split each laser beam into two beams that can be separately modulated via further electro-optical or acousto-optical modulators.

It has been emphasized that the processing of the material in Figs. 36, 36a, 36b, 36c and 37 should occur with the deflected laser beams and that the radiation

contained the non-deflected ray laser beam is to be neutralized, so that no processing effect is produced. This, however, is not absolutely necessary, and instances are conceivable wherein one works conversely. A further advantage of the arrangement shall therefore be cited and explained with reference to Fig. 36a wherein one wishes to employ the radiation contained in the laser beams I_0 for processing material, the mirror 166 is removed. The entire radiant power from all four lasers F_1 through F_4 thus derives on the generated line in a spot. More than four times the power density thus derives in the spot compared to the previous processing points B_1 through B_4, and it can be assumed that no processing effect arises in B_1 through B_4 given specific materials and process parameters. Ie., the processing surface simultaneously serves as a sump for the radiation that is not intended to produce any processing effect. This is advantageous since a thermal equilibrium occurs on the processing surface since the entire laser energy is supplied to the processing surface in every case. It lies within the scope of the invention that fewer or more than four lasers with corresponding modulator channels are utilized and that the difference in the power density between the radiation that is intended to produce a processing effect and the radiation that should not produce any processing effect is increased per modulation channel by employing more than one frequency per modulator channel. It also lies within the framework of the invention that the described principle can be advantageously applied when the laser beam incident into the acousto-optical modulator has high divergence, as is the case, for example, when the acousto-optical modulator in an arrangement according to Fig. 31 is to be arranged in the proximity of the focal point 201 or in arrangements wherein the laser has an especially great divergence. In Fig. 31, for example, the axis of the beam bundle emerging from the laser F_2 is intended to represent the position of the optimum Bragg angle for a specific frequency. In this case, the Bragg condition is met far more poorly for the one frequency for the rays at the edge of the ray bundle, for example of the lasers F_1 and F_3, than for the central rays of, for example, the laser F_2, and only a slight part of the radiation is deflected, which means low contrast for the modulator. When,

however, a plurality of frequencies are simultaneously applied to the acousto-optical modulator and when these frequencies are selected such that they are optimum both for the outer as well as for the middle incident beam bundle with respect to the Bragg angle, the highest possible contrast derives and the highest possible difference in the power density arises on the processing surface between the radiation that is intended to produce a processing effect and the radiation that should not produce any processing effect.

Fig. 38 shows how a smart arrangement of the components in the optical beam path can see to it that the laser beam bundles never perpendicularly impinge the optical surfaces. This prevents a part of the radiation from being reflected from these surfaces back into the lasers. When energy proceeds back into a laser, an excitation occurs in the laser and the laser begins to oscillate in terms of the amplitude of the radiation that is output. The output power is thus no longer constant and patterns are formed in the process surface that can make the result unuseable. Fig. 38 shows the axial rays of two planes; the lasers, however, can also be arranged in one or more planes as long as the symmetry axis for the two axes that are shown is not used. For reasons of function, the acousto-optical modulator is already turned by the angle α_B. In order, however, to be certain that energy is not reflected back into the laser as a consequence of the changing ultrasound field, the modulator can be additionally turned by the angle γ, as shown in Fig. 38. Another possibility for avoiding oscillations of the laser is the insertion of one or more optical components at suitable locations in the beam path that only allow laser radiation to transmit in one direction. For example, what are referred to as Faraday isolators can be employed for this purpose, as described under Fig. 20 in the catalog of Spindler and Hoyer on page F2. Such isolators are not shown in the Figures.

Fig. 39 shows a lens 101 whose mount contains bores 87 that preferably surround the lens in a plurality of turns and have a coolant flowing through them. Given high-power arrangements, the absorption of the optical medium of the lenses cannot be left out of consideration. Moreover, a slight part of the radiation

is dispersed by every optical surface even given the best anti-reflection coated and is absorbed by the mount parts. A cooling of the lens mounts is therefore meaningful. It has already been mentioned that materials having high thermal conductivity and low absorption such as, for example, sapphire are advantageous for the most stressed lenses. Sapphire also has the advantage that the lens surface does not scratch when cleaning due to the greater hardness of the material. One should also see to a good contacting of the optical medium with the mount. This is advantageously achieved by a metallization of the edge zone of the optical element and by a soldering 223 to the mount. Metallic solders contain a better heat conduction than glass solders.

It is also possible to cool the critical component parts of the laser gun 23 and of the pump source 2 with the assistance of what are referred to as micro-channel coolers, as described in the article "Lasers in Material Processing" in the publication SPIE Proceedings, Vol. 3097, 1997.

Fig. 39a shows a section through an inventive mount 118 for the objective lens 61, 103, 112 that, for example, is secured with a thread to the tube body 95, 96 or to the mount 116 and is sealed with a seal 125. The objective lens can be glued into the mount or, preferably can be metallized at its edge and soldered into the mount. The mount can be provided with one or more bores 120 through which a protective atmosphere that comes from the interior of the optical unit 8 flows and, for example using a channel 119, is conducted via the side of the objective lens 61, 103, 112 pointing toward the processing surface in order to prevent a contamination of the objective lens by particles of material or by gases that are released during the processing.

Fig. 40 describes a further possibility for preparing fiber lasers or optical fibers, preferably single-mode fibers, for an arrangement in tracks and planes with small spacing. The fiber 28 or laser fiber 5 is ground on all sides at the last end to such an extent that a side length arises that is reduced to such an extent that the exit points of the laser radiation 13 lie at a required, slight spacing. In this case, the terminators 26, 94 can be omitted, and an especially simple structure derives.

The surfaces that reside opposite can thereby proceed in pairs parallel to one another or at an angle, or one pair proceeds parallel and the other pair proceeds at an angle relative to one another, as was already described for the terminators under Figs. 9 and 10.

Fig. 40a shows a plan view onto, or a cross-section through the ground laser fiber. The cross-section can preferably be rectangular or quadratic; however, it can also have all other shapes.

Fig. 40b shows a side view of the fiber bundle wherein the fibers were processed similar to Fig. 40, so that the axes of the individual beam bundles 13 proceed nearly parallel.

Fig. 40c represents a side view of the fiber bundle wherein the fibers were processed wedge-shaped, so that the axes of the individual ray bundles 13 intersect outside the fiber bundle.

Fig. 40d again shows a side view of the fiber bundle wherein the axes of the individual fibers in fact proceed parallel but the exit faces of the individual fibers are arranged at different angles ε relative to the fiber axis, so that the axes of the individual ray bundles 13 intersect within the fiber bundle.

Fig. 41 shows how a receptacle with four tracks can be produced from ground fibers or laser fibers according to Fig. 40 and Fig. 40a, Fig. 40b, Fig. 40c, 40d. A receptacle in a plurality of planes is shown in broken lines in Fig. 41 in the form of two further planes. The receptacle is also not limited to four tracks and three planes; the laser outputs can be arranged in an arbitrary number of tracks and planes according to this principle. On the basis of a corresponding shaping when grinding the fibers, it is possible to determine the spacings between the exit points of the laser radiation 13. For example, the spacing can be implemented such that the laser radiation of the individual plans overlaps on the processing surface 81 such that only tracks derive or such that the individual tracks overlap so that only planes derive. The spacings between the exit points of the laser radiation 13, however, can also be selected such that the laser rays of all

tracks and all planes overlap in a point on the processing surface. For this purpose, the fiber lasers or optical fibers can also be arranged in a bundle.

The principle of the described arrangement of laser outputs in a plurality of planes or in a plurality of tracks or in a plurality of tracks and in a plurality of planes or overlapping in a point also inventively applies to the laser rays incident on the processing surface 81. A plurality of tracks or a plurality of levels or a plurality of tracks and a plurality of levels of laser beams can likewise be arranged on the processing surface according to this ordering principle or the laser beams can be arranged overlapping in a point.

The arrangement according to Figs. 40, 40a, 40b, 40c, 40d and 41 is particularly suited for directly modulatable lasers. However, external modulators can also be employed. The emerging beam bundles can be imaged into the processing surface with the known arrangements; however, a receptacle can also be implemented, whereby the beam bundles are directly directed onto the processing surface, i.e. without transmission unit, in that, for example, the outputs of a laser radiation source according to Fig. 41 are brought extremely close to the processing surface or lie on the surface of the material in sliding fashion, this yielding an especially simple arrangement. Such a method can be employed, for example, when changes in the surface of the material are to be excited by energy irradiation or when a material transfer is to be undertaken. In the example of a material transfer, a thin film is placed onto the material to be provided with images that, for example, can be a printing cylinder, an offset plate, an intermediate carrier or the material to be printed itself, a layer being applied to the underside of said thin film that faces to the material to be provided with images and that is stripped by energy irradiation and can be transferred onto the material to be provided with images.

Fig. 42 shows another embodiment of the laser radiation source that can be employed for multi-channel cutting and incising of, for example, semiconductor materials and as disclosed in German Patent Application P 198 40 936.2 of the assignee "Anordnung zum mehrkanaligen Schneiden und Ritzen von Materialien

mittels Laserstrahlen" running parallel with and filed simultaneously with the present patent application. The terminators 26, 94 of the fibers or, respectively, fiber lasers F_a through F_n have ray bundles 144 that are focused with the lens 133 at a predetermined distance from the terminator. The diameter of the processing points B_a through B_n amounts, for example, to 20 µm; however, it can also lie thereabove or therebelow. Further, the terminators are arranged on a profiled rail 256 described in greater detail in Figs. 42 and 42b such that their mutual spacing "A" can be set to arbitrary values until the terminators meet one another. The profile rail is preferably secured to an arm of a robot (Fig. 42c) and can, for example, be moved in the directions x, y, z relative to ta table 225 with actuating drives that are shown in Figure 42c. Moreover, the profiled rail can be turned relative to the table by an angle φ having the axis z' (Fig. 42c), which can also be utilized for determining the mutual spacing of the processing tracks. In the exemplary embodiments according to Figs. 4, 4b, 4c, 43, 44, the laser gun is turned around the axis of the tube 51, 95, 113 in order to vary the spacings between the processing tracks. Further, the table can be moved in the directions x, y, z and can be turned by an angle φ with the axis z. The material to be processed, for example one or more, what are referred to as "wafers" separated from a drawn semiconductor ingot, can be secured on the table 225 with clamp or suction devices (not shown). For example, fine, parallel tracks as needed, for example, for contacting photo-voltaic cells, can be incised into the semiconductor material with the laser energy in the individual processing points B_1 through B_n. However, fine bores can also be introduced into the semiconductor material or it can be cut with the laser in order, for example, to thus separate electrical circuits from one another. An inventive arrangement for removing the material 249 (Fig. 42c) eroded from the processing surface is attached close to the processing surface 81 for each processing track 224 separately or for a plurality of processing tracks 224 in common, the functioning of said arrangement being described in detail in Fig. 34. When the profiled rail with the terminators is turned relative to the table in order to modify the spacing between the processing tracks, it is inventively

expedient to compensate the distortion of the pattern to be registered that arises due to the relative rotation by a pre-distortion of the pattern to be applied and/or to compensate it with a time control of the data stream. On the basis of the turning, it is also possible to intentionally provide different line spacings given relative motions in x-direction and in y-direction. For contacting of the photo-voltaic cells, for example, two different line patterns are required: a first pattern wherein the incised lines following the metallization produce the contact to the semiconductor material should have spacings of a few millimeters between the individual lines and should, for example, proceed in the x-direction. Further, what are referred to as bus bars are required that proceed at a right angle relative to the contact lines and connect these to one another. These lines forming the bus bars should, for example, proceed in the y-direction and lie close to one another so that they act like a closed band following the metallization. Inventively, such a pattern can be very simply manufactured in that the profiled rail with the terminators is turned to such an extent until the desired pattern results. Due to the parallel arrangement of a plurality of fiber laser outputs, the time required for the processing can be considerably shortened; for example, ten laser outputs can be employed in parallel for the incising of the photo-voltaic elements 10, this increasing the output by the factor of 10.

The described arrangement for cutting and incising is not only suitable for processing semiconductor materials but can be employed for all materials wherein the precise production of patterns is important such as, for example, in manufacturing printing forms.

Fig. 42a and the corresponding sectional view of Fig. 42b show how the terminators 26 of the individual fiber lasers F_a through F_n are secured. The profiled rail 256 is secured to a carrier 260 with connections 261, the carrier potentially being, for example, the arm of a robot. The terminators 26 are accepted in mounts 257 and fixed with screw 259. The mounts 257 are provided with a profile mating with the profiled rail 256, are placed in a row onto the profiled rail 256, are set at predetermined intervals "A" from one another and are

fixed with the screws 259. Due to an inventively small structure of the terminators 26 and of the mounts 257, a very slight spacing"A" is possible. The profiled rail with the terminators can be conducted across the processing surface with the robot for the purpose of processing the material, as shown in Fig. 42 and described in detail. The required movements for producing the processing tracks can be executed by the table 225 described in Fig. 42 that can also be carried out by the arm of the robot. Preferably, the arm of the robot can also undertake a rotatory motion around the rotational axis z' of the arrangement that is approximately parallel to the axis of the terminators. With this rotation and a relative displacement between the arm of the robot and the table 225, it is possible to modify the spacing of the processing tracks generated on the processing surface 81 and to preferably set them smaller than corresponds to the dimension "A" that has been set.

Fig. 42c indicates an example of the robot that can be constructed, for example, of components of Montech-Deutschland GmbH, Postfach 1949, 79509 Lörrach. A horizontal-linear unit 263 is secured on a stand system "Quickset" 262, the unit 263 in turn accepting a vertical-linear unit 264 having a rotatory drive 265. The actual robot arm 260 is seated at the rotatory drive, the profiled rail 256 being secured to the arm 260 with the connection 261. Another horizontal-linear unit is possible but not shown.

The various motion directions of the table 225 can be realized with the same element, whereby the motion directions can also be partly allocated to the table and partly to the profiled rail. The housing for the acceptance of individual components, the cooling system, the control for the lasers, the pump sources for the fiber lasers, and the terminators 26, 94 are shown, the arrangement for removing the material eroded from the processing surface and the machine control for the drives are not shown in the Figures.

Fig. 43 shows a further flatbed arrangement with the inventive laser radiation source. The material to be processed with the processing surface 81 is located on a table 247 that is seated on guides 251 and can be moved in the feed

direction u precisely with a spindle 252. The spindle 252 is placed into rotation by a motor 254 via a gearing 253 that is driven proceeding from a control electronics 255. The laser radiation emerging from the laser gun 23 generates the processing points B_1 through B_n in an intermediate image plane 228 (not shown here) that, for example, is shown in Fig. 44. The laser radiation is conducted via deflection mirror 241 and an optics 242 belonging to an optical unit onto a rotating mirror 243 that, for example, can have one mirror face that, however, can also be designed as a rotating mirror having a plurality of mirror faces and that is placed into a rotatory motion by a motor 244 driven proceeding from the control electronics 255. The rotating mirror 243 steers the laser radiation over the processing surface line-by-line in arrow direction v. An optics 245 belonging to the optical device is located between the rotating mirror and the processing surface, the job of the optics 245 being to generate a sharp processing spot on the processing surface over the entire line length, this processing spot being potentially composed of a plurality of processing points B_1' through B_n' that are shown in Fig. 43. As a result of the rotation of the rotating mirror, the processing points generate processing tracks 224 on the processing surface 81 as shown, for example, in Figs. 35, 36 and 37. Preferably, a long deflection mirror 246 is provided between the processing surface 81 and the optics 245 in order to achieve a compact structure. The laser gun 23 is preferably turned in the prism 248 such that the processing tracks have the desired spacing from one another on the processing surface, this being shown in Fig. 35. The fixing of the laser gun can occur with a strap retainer (not shown). An inventive arrangement 249 for removing the material eroded from the processing surface is attached close to the processing surface 81 over the entire line length, the arrangement 249 being capable of being provided with a glass plate 230 over the entire length and being shown in greater detail in Fig. 43b. In Fig. 43, a laser gun with the lenses 102 and 103 according to Fig. 4b and a beam path illustrated in Fig. 20 can be provided; however, all other types of inventive laser guns can also be used. Further, a plurality of laser radiation sources can be attached in such a flat bed arrangement

in order to speed the processing procedure up. Inventively, a second laser radiation source with the corresponding optics and the arrangement 249 for removing the material eroded from the processing surface can be attached opposite the illustrated arrangement such that further processing tracks derive on the processing surface.

It lies within the framework of the invention that the rotating mirror can also be replaced by an oscillating mirror. It also lies in the scope of the invention that the rotating mirror can be replaced by two oscillating mirrors, whereby the oscillatory direction of the one mirror, called "mirror u", lies on the processing surface 81 in the direction referenced u, and whereby the oscillating direction of the other mirror called "mirror v", lies on the processing surface 81 in the direction referenced v.

An arrangement having oscillating mirrors is especially well-suited for fast incising of photo-voltaic cells, as was described in detail under Fig. 42. The cell to be incised is placed onto the table 247 with, for example, a loading device that is not shown in Fig. 43 and is brought into the correct position. The laser gun 23 is turned such that the desired spacings in the processing tracks arise in the two processing directions u and v. In a first processing event, for example, mirror u draws the contact lines, whereas mirror v undertakes the correct positioning of the contact line packets. In a second processing event, mirror v draws the bus bars, whereas mirror u undertakes the correct positioning of the line packets. In these processing events, the photo-voltaic cell is not moved. It lies within the scope of the invention that the table 247 can be replaced by a magazine (not shown) wherein a specific number of photo-voltaic cells are delivered for processing, that the processing of the respective cell occurs directly in the magazine, and that the processed cell is automatically removed from the magazine after the processing and is transferred into a second magazine, whereby the next, unprocessed cell for processing moves forward to take the place of the removed cell.

As a result of the extremely high beam quality of the laser radiation source that derives due to the fiber laser working diffraction-limited, a nearly parallel

laser beam bundle can be generated, as shown in Fig. 43 between the optics 242 and rotating mirror 243 and as can also be seen in Fig. 4 between the lenses 57 and 61. Consequently, it is also possible to remove the optics 245, the rotating mirror 243 and the deflection mirror 246 in Fig. 43 and replace them by a deflection mirror (not shown) that deflects the nearly parallel laser beam bundle emerging from the optics 242 in the direction of the processing surface 81 and onto an objective lens (not shown) having a short focal length that is implemented similar to the objective lenses 61, 103 or 112.

The deflection mirror and the objective lens are inventively combined with one another to form a unit and slide back and forth on a guide rail (not shown) in the direction v, so that a number of parallel processing tracks corresponding to the number of channels in the laser radiation source are registered on the processing surface (81) similar to previously with the rotating mirror 243 and the optics 245.

Inventively, the guide rail is implemented as a bearing having very low friction, for example as an air bearing or as a magnetic bearing. The drive of the unit composed of the objective lens and the deflection mirror in the direction v and back respectively occurs with a thrust into the corresponding direction that, for example, is carried out by a preferably contact-free electromagnetic system, whereby the energy acquired from the deceleration of the moving unit is partially re-employed for the drive. Parts of the guide rail, deflection mirror and objective lens are, for example, accommodated in a closed space that contains windows for the entry and the exit of the laser radiation and can be evacuated in order to reduce frictional losses. The drive and guide rail represent a linear drive for the unit composed of the objective lens and the deflection mirror.

It lies within the framework of the invention that the respective, true position of the moving unit can be determined for correction purposes via, for example, an optical reference track. An arrangement 249 serves for the removal of the material eroded from the processing surface 81. The advantage of such an arrangement is that it can be very cost-beneficially realized for long path lengths and high resolutions, and that it can be set to various formats by displacement of

the one and/or other drive. A plurality of such units can also be arranged in parallel in order to increase the processing speed.

Fig. 43a shows a simplification of the arrangement according to Fig. 43 in that the two lenses 102 and 103 have been removed from the laser gun. Given a corresponding spacing of the laser gun from the deflection mirror 241, the divergent laser ray bundles emerging from the lens 101 are focused onto the processing surface 81 with the lenses 241 and 245 and generate the processing points B_1 through B_n that are identical to the processing points B_1' through B_n' in this case.

Fig. 43b shows the arrangement 249 for removing the material eroded from the processing surface in greater detail. The functioning has been described in detail in Fig. 34.

Fig. 44 shows a hollow bed arrangement for processing material with the inventive laser radiation source. Hohlbett arrangements are known; for example, two arrangements having hollow bed are described in the publication "Der Laser in der Druckindustrie" by Werner Hülsbuch, Verlag W. Hülsbusch, Konstanz, pages 461 and 562. The material to be processed with the processing surface 81 is located in a cylinder or, preferably, a part of a cylinder 236 having the radius R. This arrangement is referred to as a hollow bed on whose axis a bearing 229 with a rotating mirror 233 is arranged. The rotating mirror can, for example, have one mirror face but can also be designed with a plurality of mirror faces and can be placed into rotation by a motor 234 and be arranged on a carriage (not shown) displaceable in the direction of the cylinder axis relative to the cylinder 236. An optics 231 belonging to an optical device and a mirror 232 are arranged as well on the carriage (not shown) in the proximity of the processing surface 81. Further, a deflection mirror 227 and the laser gun 23 as well as an arrangement 235 - close to the processing surface 81 - for removing the material eroded from the processing surface, which is described in greater detail in Fig. 34, are located on the carriage. The ray bundles 226 emerging from the laser gun generate processing points B_1 through B_n in an intermediate image plane 228 that are

transmitted onto the processing surface 81 with the deflection mirror 227, the mirror optics 231, 232 and the rotating mirror 233. Here, they generate the processing points B_1' through B_n'. The processing points B_1' through B_n' that form the processing spot generate processing tracks 224 (Figs. 35, 36 and 37) across the entire line length that are registered sharply focused over the entire line length as a result of the constant radius of the hollow bed. The advantage of the illustrated arrangement is that a compact structure can be achieved. In particular, the illustrated arrangement enables a small angle δ between the axis of the ray bundle incident onto the rotating mirror 233 and the ray bundle that is reflected by the rotating mirror onto the processing surface, which is desirable for low distortion in the recording geometry on the processing surface. The laser gun is preferably seated in a prism (not shown) and is secured with a fastening strap (likewise not shown). The laser gun can be turned around its axis and can be displaced in the axial direction. As a result of the rotation, the distance between the processing tracks can be modified, this being shown in Fig. 35. The spacing from the processing surface can be modified by the displacement. An inventive arrangement 235 for removing the material eroded from the processing surface is attached over the entire line length close to the processing surface 81, the arrangement 235 being capable of being designed similar to what is shown in Fig. 43b, whereby it is implemented in curved fashion corresponding to the radius R of the cylinder 236 and can be provided with a curved glass plate 237 (not shown) over the entire length, the functioning thereof having been described in detail under Fig. 34. In Fig.44, a laser gun having the lenses 102 and 103 according to Fig. 4b and a beam path shown in Fig. 20 are provided. However, all other types of the inventive laser gun can be utilized. Further, a plurality of laser radiation sources can also be attached in such a hollow bed arrangement in order to speed the processing event up. For example, a second rotating mirror and a second laser radiation source as well as a second arrangement 235 for removing the material eroded from the processing surface can be attached opposite the illustrated arrangement such that further processing tracks derive on the processing surface.

Fig. 44a shows a simplification of the arrangement according to Fig. 44, in that the two lenses 102 and 103 were removed from the laser gun. Given a corresponding spacing of the laser gun from the deflection mirror 227, the divergent laser ray beams emerging from the lens 101 are focused onto the processing surface 81 with the lens 231 and generate the processing points B_1 through B_n that are identical to the processing points B_1' through B_n' in this case.

While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only the preferred embodiment has been shown and described and that all changes and modifications that come within the spirit of the invention are desired to be protected.

Abstract

In a laser radiation source, preferably for processing material, as well as to an arrangement for processing material with the laser radiation source and to the operation thereof, for achieving a high power density and energy, the laser radiation source comprises a plurality of diode-pumped fiber lasers whose outputs are arranged in a bundle. The laser radiation emerging from the outputs of the fiber lasers is merged and bundled with an optical unit such that the laser radiation is incident onto a processing surface at a processing spot .

SPECIFICATION

TITLE

LASER RADIATION SOURCE

BACKGROUND OF THE INVENTION

The invention is directed to a laser radiation source, preferably for processing materials, as well as to an arrangement for processing material comprising a laser radiation source and to the operation thereof.

When processing materials with focused energy beams such as, for example, electron beams or laser beams, there are applications wherein structures must be produced that make high demands of the focused energy beam with respect of its beam geometry and the focusability of the beam. At the same time, however, a high [steel] <u>beam</u> power is required.

A typical case wherein extremely fine structures must be produced on a processing surface is the production of printing forms, whether for rotogravure, offset printing, letter press printing, silk screening or flexo-printing or for other printing processes. In the production of printing forms, it is necessary to produce extremely fine structures on the surface of the printing forms, since highly resolved image information such as text, screened images, graphics and line work must be reproduced with the surface of the printing forms.

In rotogravure, the printing forms were produced in the past with etching, which had led to good results; the etching, however, was replaced over the course of time by more environmentally friendly engraving with electromagnetically driven diamond stylii. Printing cylinders whose surface is composed of copper are normally employed as printing forms in rotogravure, these fine structures required for the printing being engraved thereinto in the form of cups with the diamond stylus. The printing cylinders are introduced into a printing press after they are produced, the cups being filled with ink therein. Subsequently, the excess ink is removed with a doctor blade and the remaining ink is transferred

onto the printed matter during the printing process. Copper cylinders are thereby employed because of their long service life in the printing process. A long service life is required given large editions, for example, in particular, in magazine printing or packaging printing, since the surface of the printing form wears in the printing process as a result of the influence of the doctor blade and of the printed matter. In order to extend the service life even further, the printing cylinders are provided with a copper layer that has been galvanized on; on the other hand, solid cylinders of copper are employed. Another possibility of making the service life even longer is comprised in galvanically chrome plating the copper surface after the engraving. In order to achieve an even longer [surface] <u>service</u> life, what is referred to as "hot chrome plating" is additionally applied, whereby the galvanic process is carried out under elevated temperature. The longest service lives that could previously be obtained were achieved therewith. Deriving therefrom is that copper is the most suitable as the material for the surface of rotogravure cylinders. Materials other than copper have not hitherto proven themselves for large editions.

When producing the cups, the drive of the diamond stylus occurs via an electromechanically driven magnet system having an oscillating armature to which the diamond stylus is secured. Such an electromechanical oscillatory system cannot be made arbitrarily fast because of the forces that must be exerted in order to engrave the cups. This magnet system is therefore operated above its resonant frequency so that the highest engraving frequency, i.e. the highest engraving speed can be achieved. In order to increase the engraving speed even further, a number of such engraving systems have been arranged side-by-side in the axial direction of the copper cylinder <u>in</u> given current engraving machines. This, however, still does not suffice for the short engraving time of the printing cylinders required currently, since the engraving time directly influences the [current nature] <u>actuality</u> of the printing result. For this reason, rotogravure is not employed for newspaper printing but mainly for magazine printing.

Upon utilization of a plurality of engraving systems, a plurality of what are referred to as lanes are simultaneously engraved into the surface of the printing cylinder. For example, such a lane contains one or more entire magazine pages. One problem that thereby arises is that cups having different volumes are generated in the individual lanes given the same tone value to be engraved, this occurring because of the different engraving systems that are driven independently of one another and leading to differences in the individual lanes that the eye detects during later observation. For this reason, for example in packaging printing, only one engraving system is employed so that these errors, which are tolerated in magazine printing, do not occur.

When engraving the cups, the cup volume is varied dependent on the image content of the master to be printed. The respective tone value of the master should thereby be reproduced as exactly as possible during printing. When scanning the masters, the analog-to-digital converters having, for example, a resolution of 12 bits are utilized for recognizing the tone value gradations for reasons of image signal processing (for example, gradation settings), this corresponding to a resolution of 4096 tone values in this case. The signal for the drive of the electromagnetic engraving system is acquired from this high-resolution image information, said signal usually being an 8-bit signal corresponding to a resolution into 256 tone value gradations. In order to generate the corresponding volumes that are required for achieving this scope of gradations, the penetration depth of the diamond stylus into the copper surface is varied with the drive of the magnet system, whereby the geometry of the cups changes between approximately 120 µm diameter given a depth of 40 µm and approximately 30 µm diameter given a depth of 3 µm. Because only an extremely small range of variation in the depth of the cups between 40 µm and 3µm is available, the penetration depth of the stylus with which the cups are engraved must be exactly driven to fractions of a µm in order to reproducibly achieve the desired range of gradation. As can be seen therefrom, an extremely high precision is required in the engraving of the cups, at least as regard to the generation of the

required diameters and depths of the cups. Since the geometry of the engraved cups is directly dependent on the shape of the stylus, extremely high demands are also made of the geometry of the diamond stylus which, as has been shown, can only be achieved with extremely high expense and with a high rejection rate in the manufacture of the stylii. Moreover, the diamond stylus is subject to wear since, when engraving a large printing cylinder having fourteen lanes, a circumference of 1.8m and a length of 3.6m given a screen of 70 lines/cm - which corresponds to a plurality of 4900 cups/cm^2, a stylus must engrave approximately 20 million cups. When one of the diamond stylii breaks off during the engraving of a printing cylinder, then the entire printing cylinder is unuseable. On the one hand, this causes a considerable financial loss and, on the other hand, represents a serious loss of time since a new cylinder must be engraved, postponing the start of printing by hours. For this reason, users frequently replace stylii earlier than necessary. As can also be seen therefrom, the endurance of the diamond stylii is also a critical concern.

All in all, electromagnetic engraving is well-suited for producing high-quality rotogravure cylinders; however, it has a number of weak points and is extremely complicated and one would like to eliminate these disadvantages with a different method.

The cups produced in this way, which are intended to accept the ink later, are also arranged on the surface of the printing form in conformity with a fine, regular screen, namely the printing screen, whereby a separate printing cylinder is produced for each ink, and whereby a different screen having a different angle and different screen width is respectively employed. When printing in the printing press, given these screens, narrow [webs] <u>bridges</u> remain between the individual cups, these supporting the doctor blade that removes the excess ink after the inking. Another disadvantage of this operating mode of this electromechanical engraving is that texts and lines must also be reproduced in screened fashion, which leads to step-patterns in the contours of the written characters and the lines that the eye perceives as being disturbing. This is one [advantage] <u>disadvantage</u>

compared to the widespread offset printing wherein this stepping can be kept an order of magnitude lower, which can then no longer be perceived by the eye, and which leads to a better quality that rotogravure could hitherto not achieve. This is a serious disadvantage of the rotogravure process.

In rotogravure, no stochastic screens can be generated wherein the size of the cups and the position of the cups can be randomly distributed corresponding to the tone value; this is not possible when engraving with the diamond stylus. Such stochastic screens are also frequently referred to as "frequency-modulated screens" that have the advantage that details can be reproduced far better with no Moirè, this also leading to a better image quality than in rotogravure.

It is also known to utilize the electron beam engraving method applied in the processing of materials for generating the cups, this having exhibited extremely good results because of the high energy of the electron beam and the incredible precision with respect to the beam deflection and beam geometry.

This method is described in the publication, "Schnelles Elektronenstrahlgravierverfahren zur [Grvur] <u>Gravur</u> von Metallzylindern", Optik 77, No. 2 (1987) pages 83-92, Wissenschaftliche Verlagsgesellschaft mbH Stuttgart. Due to the extremely high expense that is required for the hardware and electronics, electron beam engraving has hitherto not prevailed in practice for the engraving of copper cylinders for rotogravure but only in the steel industry for surface engraving of what are referred to as textured drums for sheet metal manufacture wherein textures are rolled into the sheets.

It has been repeatedly proposed in the trade literature as well as in the patent literature to engrave copper cylinders with lasers. Since copper, however, is an extremely good reflector for laser radiation, extremely high powers and, in particular, extremely high power densities of the lasers to be employed are required in order to penetrate into the copper and [melted] <u>melt it</u>. There has hitherto not been any laser engraving unit with laser radiation sources having a correspondingly high [powered] <u>power</u> density and energy with which one

succeeds in providing the copper cylinders for rotogravure with the required cup structure in the copper surface.

Attempts have nonetheless been made to utilize lasers for rotogravure in that a switch has been made to materials other than copper. Thus, for example, the publication DE-A-19 20 323 has proposed to prepare copper cylinders with chemical etching such that the surface of the copper cylinder already comprises cups that have a volume that corresponds to the maximum printing density. These cups are filled with a solid filler material, for example plastic. Much of the filler material is then removed with a laser until the desired cup volume has been achieved. This method in fact manages with a lower laser power than would be necessary in order to melt and evaporate the copper as in electron beam engraving. In this method, however, the remaining plastic is attacked by the solvent of the ink in the printing process and is decomposed, so that only a low print run is possible. This method has not proven itself in practice and has thus not been utilized.

The publication of the VDD Seminar Series, "Direktes Lasergravierverfahren für metallbeschichtete Tiefdruckzylinder", published within the framework of a "Kolloquium vom Verein Deutscher Druckingenieure e.V. und dem [fachgebiet] Fachgebiet Druckmaschinen und Druckverfahren, Fachbereich Maschinenbau, [technische] Technische Hochschule Darmstadt", by Dr. phil. Nat. Jakob Frauchiger, MDC Max Dätwyler, AG, Darmstadt, 12 December 1996, has proposed that rotogravure cylinders plated with zinc be engraved by a quality-switched Nd:YAG high-power solid-state laser pumped with arc lamps. In this method, the volume of the cups is defined by the optical power of the laser. The laser power required for the engraving is transmitted onto the cylinder surface via an optical fiber whose output is imaged onto the cylinder surface through a variable focusing optics. One disadvantage of this method is that the arc lamps required for pumping the laser have a relatively short service life and must be replaced after approximately 500 hours of operation. The engraving cylinder becomes unuseable given a failure of the pump light source

during the engraving. This corresponds to a failure of the diamond stylus in electromechanical engraving and results in the same disadvantages. A preventative replacement of the arc lamps is cost-intensive and work-intensive, particularly since one must count on the fact that the laser beam must be re-adjusted in position after the replacement of the lamps. These lamp-pumped solid-state lasers also have a very poor efficiency since the laser-active material absorbs only a slight fraction of the available energy from the pump source, i.e. from the arc lamp here, and converts into laser light. Particularly given high laser powers, this means a high electrical connection cost, high operating costs for electrical energy and cooling and, in particular, a considerable expense for structural measures due to the size of the laser and the cooling unit. The space requirements are so high that the laser unit must be located outside the machine for space reasons, this in turn being accompanied by problems in bringing the laser output onto the surface of the printing cylinder.

A critical disadvantage of this method is that zinc is significantly softer than copper and is not suitable as a surface material for printing cylinders. Since the doctor blade with which the excess ink is removed before printing in the printing press is a steel blade, the zinc surface is damaged after a certain time and the printing cylinder becomes unuseable. A printing cylinder having a surface of zinc therefore does not even begin to approach as long a service life in printing as a printing cylinder having a surface of copper. Printing forms having a zinc surface are therefore not suitable for high press runs.

Even if the zinc surface is chrome-plated after the engraving, as has been also proposed in order to lengthen the service life, the durability does not come close to that of normal copper cylinders. Chrome does not adhere to zinc as well as it adheres to copper and what is referred to as "hot chrome plating", which is successfully employed given copper cylinders in order to achieve an optimum adhesion of the chromium on the copper, is not possible given zinc since the zinc would thereby melt. Since the chrome layer does not adhere very well on the zinc, it is likewise attacked by the doctor blade, which leads to a relatively early

failure of the printing cylinders. When, in contrast thereto, copper cylinders are chrome-plated according to this method, then incredibly high press runs are possible since the chromium firmly adheres on the copper surface, so that these copper cylinders out perform the chrome-plate zinc cylinders by far.

It proceeds from the publication EP-B-0 473 973, which is likewise directed to the method described above, that an energy of 6 mWsec is required in this method given zinc for cutting a cup having a diameter of 120 μm and a depth of 30 μm. An energy of 165 mWsec is recited in this publication for copper, this amounting to a factor of 27.5 for the required laser power. Lasers having a continuous-wave performance of several kilowatts given good beam quality are thus required in order to produce cups in copper with a speed that is accessible for the printing industry. Such a power, however, cannot be produced with the laser arrangement described above. For this reason, it is likewise only possible to engrave a zinc surface.

Such a laser arrangement, which is composed of a single solid-state laser, in fact makes it possible to process rotogravure cylinders having a zinc surface; if, however, one wishes to utilize the advantages of the copper surface and stay with copper cylinders and engrave these with a laser, the high power density required for penetration into the surface of the copper and the high energy required for melting the copper must be inevitably exerted. This, however, has not hitherto been successfully done with a solid-state laser.

It is known that the beam quality in solid-state lasers, i.e. the focusability, decreases with increasing power. Even if the power of the solid-state lasers were to be driven up or if a plurality of solid-state lasers were directed onto the same cup or parts thereof, it would therefore not be possible to satisfactorily engrave copper cylinders for rotogravure with such a laser because the precision of the laser beam, as offered by the electron beam, required for generating the fine structures cannot be achieved. If the laser power were increased given this apparatus, then a further problem would arise: the focusing of high radiant intensity [in] <u>into</u> optical fibers is, as known, difficult. The fibers burn at high

power as a consequence of misadjustment at the infeed location. If one wishes to avoid this, however, the fiber diameter would have to be enlarged which, however, in turn has the disadvantage that the fiber diameter would have to be imaged onto the processing [page] material with even greater demagnification. A demagnified imaging, however, leads to an increase in the numerical aperture on the processing [page] surface and, consequently, to a reduced depth of field on the processing surface. As proposed, the distance from the processing surface could be kept constant. When, however, the beam penetrates into the surface of the material, then a defocussing automatically derives. This has a disadvantageous influence on the required power density and on the exact dot size. Since, however, the diameter of the processing spot and the energy of the beam determine the size of the cup, it then becomes difficult to make the cup size as exactly as required by the desired tone value. For this purpose, it would also be necessary that the laser power is exactly constant and also remains constant over the entire time that is required for a cylinder engraving. When this is not the case, the cup size changes and the cylinder becomes unuseable. This cannot be compensated by varying the size of the processing spot since it is not possible to adequately vary the processing spot in shape.

Further, a complicated modulator is required given such an arrangement. As known, modulators for extremely high laser powers are slow, this leading to a reduction of the modulation frequency and, thus, of the engraving frequency. When, however, the engraving frequency is too low, the energy diffuses into the environment of the processing spot on the processing surface without cutting out a cup. It is therefore necessary to also exert a high power in addition to the high energy for the cutting.

The publication "Der Laser in der Druckindustrie", by Werner [Hülsbuch] Hülsbusch, page 540, Verlag W. Hülsbusch, [Constanc] Konstanz, describes that it is particularly a matter of a high [powered] power density in processing materials [given]. Given power densities of typically above 10^7 through 10^8 W/cm^2, a spontaneous evaporation of the material occurs in all materials, this

being accompanied by a sudden absorption rise, which is especially advantageous since the laser power is then no longer reflected from the metal surface. When, for example, a laser source of 100 W is available, then the processing spot [dare] diameter may not be larger than 10 μm in order to arrive at these values in the region, as proceeds from the following equation: 100 W : (0.001 cm x 0.001 cm)=10^8 W/cm^2.

SUMMARY OF THE INVENTION

One object of the present invention is to improve a laser radiation source, preferably for processing materials, as well as an arrangement for processing materials having a laser radiation source and the operation thereof such that an extremely high power density and energy are achieved in a cost-beneficial way, and such that both the beam shape with respect to flexibility, precision and beam positioning as well as the beam power can be exactly controlled even given significantly higher laser powers.

According to the present invention, a laser radiation source is provided for generating laser beams with high power density and higher energy for processing material. A plurality of [directly modulatable,] diode-[pump] pumped fiber lasers are provided having outputs arranged in a first ordering pattern. An optical unit is provided connected to the outputs of the fiber lasers wherein laser beams emerging from the outputs of the individual fiber lasers are shaped and aligned such that they impinge onto a processing surface in a second ordering pattern.

Further advantageous developments and improvements with respect to the apparatus for processing materials with the laser beam source and the operation thereof are discussed hereafter.

This laser radiation source comprises a plurality of diode-pumped fiber lasers whose output radiation beams impinge the processing location next to one another and/or over one another or in a point or bundle and thus enables the generation of a processing spot that is designationally variable in shape and size, even given extremely high laser powers and extremely high power densities. According to the invention, these fiber lasers can be implemented as continuous

wave lasers or as quality-switched lasers, also referred to as Q-switch lasers, whereby they are advantageously internally or externally modulated and/or comprise an additional modulator. Q-switch lasers have an optical modulator available to them within the laser resonator, for example an acousto-optical modulator, that, in its opened condition, interrupts the laser effect given a pump radiation that continues to exist. As a result thereof, energy is stored within the laser resonator, this being output as a short laser pulse having high power when the modulator is closed in response to a control signal. Q-switch lasers have the advantage that they emit short pulses having high power, which briefly leads to a high power density. An advantageous elimination of the molten and evaporated material is enabled in the pulsed mode due to the brief-term interruptions in the processing event. Instead of switching the quality, a pulsed mode can also be generated with internal or external modulation.

The processing spot can be designationally modified in shape and size in that different numbers of lasers are provided that can be switched on for shaping the processing spot. It is thereby especially advantageous that the depth of the cut cup can be determined by the laser energy independently of its shape and size. Further, a control of the energy of the individual lasers can also generate any arbitrary beam profile within the processing spot and, thus, any arbitrary profile within the cup as well.

Further advantages of the present invention compared to known laser radiation sources are comprised therein that the infeed of the radiant power from a solid-state laser into an optical fiber can be eliminated but the exit of the fiber laser supplies diffraction-limited radiation that, according to the invention, can be focused onto less than a 10 μm diameter, as a result whereof an extremely high power density is achieved given the greatest possible depth of field.

Given a traditional arrangement with solid-state lasers, the size of the processing spot lies in the region of approximately 100 μm. Given the present invention, thus a power density that is improved by the factor 100 derives, and a

design possibility in the area of the processing spot that is improved by the factor 100 derives.

Due to the high precision and due to the shape of the processing spot that can be designed in very fine fashion, extremely fine screens, also including the stochastic screens that are also called frequency-modulated screens (FM screens) and, thus extremely smooth edges in lines and written characters can be economically produced, so that rotogravure no longer need be inferior to offset printing in terms of printing quality.

Due to the operating mode of the laser radiation source of the invention, it is also possible to link arbitrary raster widths to arbitrary screen angles and apply arbitrary different screen widths and arbitrary different screen angles at arbitrary locations on the same printing cylinder. Line patterns and text can also be applied independently of the printing screen as long as one sees to sufficient supporting locations for the doctor blade.

One advantage of the invention is that the differences in the data editing for the production of the printing form are reduced to a minimum between rotogravure and offset printing, this yielding substantial cost and time savings. Up to now, the data for the rotogravure are acquired by conversion from the data already present for the offset printing because a signal is required for the drive of the engraving system that defines the volume of a cup, whereby the area of a screen dot is determined in offset printing. As a result of the multiple arrangement of lasers, the laser beam source of the invention makes it possible to vary the area of a cup given constant depth, for which reason it is no longer required to convert the data for offset printing into data for the rotogravure. The data for the offset printing can be directly employed for engraving the rotogravure forms.

Another advantage of the invention is that both the area of a cup as well as the depth can be controlled independently of one another with this laser [beam] radiation source, this leading to that a greater number of tone value gradations that

can be reproducibly generated, this leading to a more stable manufacturing process for the printing cylinders and to an improved printing result.

It is also [a critical] an essential advantage that the energy can be unproblemmatically transported from the pump source to the processing point with the fiber, namely the fiber laser itself, or with a fiber that is welded on or, respectively, attached in some other way, this yielding an especially simple and space-saving structure.

Another advantage of the invention is that the efficiency of such an arrangement with fiber lasers is significantly higher than the efficiency of solid-state lasers, since absorption efficiencies of more than 60% are achieved for fiber lasers, these lying only at approximately half given traditional [dialed] diode-pumped solid-state lasers and being even far lower given lamp-pumped solid-state lasers. Given the required power of several kilowatts for an efficient engraving of rotogravure cylinders, the efficiency of the lasers is of incredible significance for the system costs and the operating costs.

Further, a multiple arrangement of lasers yields the advantage that the outage of a laser is less critical than given a single-channel arrangement. When the only laser that is present given the single-channel arrangement fails during the engraving of a printing cylinder, the entire printing cylinder is unuseable. When, however, a laser fails given a multiple arrangement, then the power of the remaining lasers can, for example, be slightly boosted in order to compensate the failure. After the end of the engraving, the laser that has failed can then be replaced.

The dissertation, "Leistungsskalierung von Faserlasern", Physics Department of the University of Hannover, Dipl.-Phys. Holger Zellmer 20 June 1996, fiber lasers are discussed as being known. These lasers, however, had already been proposed in 1963 by Snitzer and Köster, without these having been previously utilized for processing materials given high powers. Although powers of up to 100 W can be fundamentally achieved with the lasers described in this

dissertation, no useable arrangements are known for utilizing these lasers for purposes of the present invention.

The publication WO-A-95/16294 has already disclosed phase-coupled fiber lasers; however, these are extremely involved in terms of manufacture and are not suitable for industrial employment. It had hitherto not been recognized to bring lasers of this simple type to high power density and energy in the proposed, simple way and to utilize them for erosive processing of materials.

For example, the resonator length of the individual lasers must be kept exactly constant to the fraction of a micrometer, for which purpose what are referred to as "piezoelectric fiber stretchers" are utilized. As a result of the complex structure, it is likewise not possible to construct the laser unit modularly, i.e. of components that are simple to assemble and to be multiply employed or to replace individual laser components as needed on site as a consequence of the great number of optical components within a phase-coupled laser. Moreover, the optical losses are extremely high, and the pump radiation absorption of the laser-active medium is low, which results in a low efficiency of the arrangement. Although fiber lasers are not particularly susceptible to back-reflections in and of themselves, phase-coupled lasers exhibit a great sensitivity to back-reflections due to their very principle, i.e. when portions of the emitted radiation proceed back into the laser resonator due to reflection or dispersion, as is unavoidable when processing materials. These back-reflections lead to uncontrolled output amplitudes and cause the laser to shut down. Although what are referred to as optical isolators are known, these being intended to attenuate such back-reflections, these involve a number of disadvantages in practice, which, for example, include the optical losses, the high price and the inadequate attenuation properties. The lasers for the purpose of the invention of processing materials need not only exhibit a high power density but also must be able to supply the required energy for cutting out the cups, must be extremely stable in terms of the emitted radiation and must have a very good efficiency.

Further, US-A-5,694,408 has disclosed a laser system wherein a master oscillator generates low-power radiation energy at a specific wavelength, this being optically intensified and it being distributed for further post-amplification onto a plurality of post-amplifiers, in order to then be in turn united to form a common beam, a precise phase readjustment of the individual post-amplified signals being required for this purpose in order to avoid interferences in the output signal. This requires complicated measuring and control procedures and involved actuating elements, for which purpose, for example, electro-optical phase modulators must be utilized, these being extremely expensive and having to be operated with extremely high voltages.

Further, US-A-5,084,882 discloses a phase-coupled laser system that employs a plurality of fibers or fiber cores in a bundle, the core thereof being, on the one hand, large compared to its cladding or its spacing in order to achieve the phase coupling; on the other hand, this should only have a diameter of a few micrometers since it is a matter of single-mode fibers. This system is mainly provided as an optical intensifier.

Another phase-coupled laser system that is likewise implemented in an extremely complex way and that is composed of a plurality of what are referred to as "sub-oscillators" is disclosed by GB-A-21 54 364 under the title "Laser Assemblies", having already been disclosed in 1984; however, no industrial realizations with such phase-coupled laser systems have become known up to now.

It has also not been previously proposed to combine a number of the initially cited fiber lasers in a simple way, i.e. without a complex phase coupling or the like, to form a compact, rugged and service-friendly radiation source for processing materials and, for example, to employ this for multi-track recording. An inventive, multiple arrangement of such simple lasers that can be cost-beneficially manufactured in quantity in several tracks and levels yields enormous advantages for the purposes of the invention that would certainly not have escaped attention if the invention solution had been known.

A further advantage of fiber lasers is [there] their clearly lower tendency to oscillate when energy proceeds back into the laser. Compared to traditional solid-state lasers, fiber lasers have a resonance overshooting that is lower by an order of magnitude in terms of its transfer function, this having been very positively proven during operation. When processing materials, namely, one cannot always prevent energy from being reflected from the processing location back into the laser because the melting material is explosively hurled in unpredictable directions and thereby flies through the laser beam before it can be removed and neutralized by particular techniques that are presented in one embodiment of the invention.

[A critical] An essential advantage of the multiple arrangement of fiber lasers without phase coupling is that the individual lasers behave differently in case of a back-reflection. This is related to the fact that, for example, some of the lasers are not affected at all by a back-reflection and others may possibly be effected only with a delay. The probability is therefore high that oscillations of the individual lasers, if they occur at all, are superimposed such that they have no negative influence on the quality of the results of the engraving.

The laser radiation source of the invention can also be advantageously utilized for all other types of processing materials or transferring materials wherein high power density, high energy and great precision or, too, high optical resolution are important. In addition to engraving rotogravure cylinders having a copper surface, other materials such as, for example, all metals, [ceramic] ceramics, glass, semiconductor materials, rubber or plastics can be processed and/or materials can be stripped from more specifically prepared carrier materials and transferred onto other materials at high speed and with high precision. In addition to those that are uncoated, moreover, rotogravure cylinders, printing plates or printing cylinders that are coated with masks as well as all types of printing forms can also be produced or, respectively, processed at high speed and with high resolution for offset printing, letter press printing, silk screening, flexo-printing and all other printing processes. For example, the offset printing

plates having metal coating (bi-metal plates) that are employed for printing extremely large print runs in offset printing and similar materials can be provided with images in an environmentally friendly way, this having been hitherto possible only with etching.

Further, materials can be processed that contain a magnetizable surface, in that the parts of the material magnetized in large-area fashion by a pre-magnetization process are de-magnetized by briefly heating selected processing points to temperatures that lie above the Curie point, when heated with the inventive laser radiation source. The material provided with images in this way for applications in printing technology can serve as a print master in conjunction with a corresponding toner.

As a result of the high power density of the inventive laser radiation source, it is also possible to directly process chromium. Thus, for example, printing cylinders of copper can already be chrome-plated for rotogravure before the laser engraving, this eliminating a work step after the engraving and benefitting the timeliness. Since the printout behavior of a cup engraved in copper is also better than that of a chrome-plated cup and its volume is more precise, this method also yields even better printing results in addition to the high service life as a result of the remaining chromium layer and the improved timeliness.

The employment of the inventive laser radiation source, however, is not limited to employments in printing technology but can be utilized anywhere that it is important to erode material or change the properties of the material by energy irradiation with lasers given high resolution and high speed. Thus, for example, the aforementioned texture drums can also be produced with the inventive laser radiation source. Further, the patterns of interconnects for printed circuit boards, including the boards for the components, preferably for multi-layer printed circuit boards, can be produced by eroding the copper laminate and allowing the interconnects to stand, and by eroding copper laminate and carriers at the locations of the bores. Further, the surface structure of material surfaces can be

partially modified by partial heating. For example, extremely fine structures [having] in the hardness of material surfaces can be produced in large-area fashion in this way, this being particularly advantageous for bearing surfaces since the bearing properties can be intentionally influenced in this way. Further, there are non-conductive ceramic materials at whose surface metal crystallizes out due to energy irradiation, this being capable of being utilized in conjunction with the inventive laser radiation source for applications that require a high resolution, for example for producing interconnects.

The laser beams can thereby be guided to the processing spot [in the greatest variety of ways] and can be moved across the material [;] in the greatest variety of ways for example, the material to be processed can be located on a rotating drum past which the radiation source is conducted in relative fashion. However, the material can also be located in a plane over which the laser radiation source or its output radiation is conducted past in relative fashion. In a flat bed arrangement as presented in the aforementioned publication "Der Laser in der Druckindustrie" von W. Hülsbusch, Figure 7-28 on page 431 and as likewise disclosed in the publication EP-A-0 041 241, the radiation source presented therein as argon or He Ne laser or, respectively, as laser light source (4) in Figure 3 of the publication can be replaced by the inventive laser radiation source in order to utilize the advantages of the inventive laser radiation source. Further, the material to be processed can be located within a hollow cylinder over which the laser radiation source or its output radiation sweeps in a relative motion.

Inventively, the output of the laser radiation source can also be implemented with a variable number of tracks whose mutual spacings are variable, preferably similar to a long comb, this moving relative to the material to be provided with images. Such an arrangement is disclosed by US-A-5,430,816. It is disclosed therein to direct the radiation of an excimer laser having a strength of approximately 50 watts onto a bundle of what are referred to as stepped index fibers having diameters of 50 through 800 micrometers and to respectively couple a part of the radiation into the individual fibers. The exit of each fiber is then

imaged onto the workpiece via a respective positive lens having a diameter of 60 mm, whereby the spacing between the individual processing points must amount to at least 60 mm and a protective mechanism to prevent contamination is required per positive lens. What is disadvantageous is that only a fraction of the laser energy thus proceeds into the respective fibers. The energy distribution turns out very differently and changes in the exit power derive given movement of the fibers, for which reason what are referred to as scramblers must be utilized in order to avoid this. These scramblers, however, disadvantageously influence the efficiency of the system and increase the costs. Only relatively imprecise bores having a diameter of approximately 130 micrometers can be produced in plastic with such an arrangement. The pulse rate of the laser is the same for all simultaneously produced bores, so that all bores must be implemented of the same size. Moreover, the system is relatively slow since a boring processing lies between one and two seconds. An arrangement having fiber lasers yields tremendous advantages compared thereto: the speed can be increased by several orders of magnitude and metals can also be processed; the precision is substantially greater since fiber lasers also exhibit a stable output power given movement of the laser fibers; and bores having diameters below 10 micrometers can also be unproblemmatically produced. Since each fiber laser can be separately modulated, different processing patterns are possible. Further, the end sections of the fiber lasers can be unproblemmatically implemented smaller than 2.5 mm in diameter, this enabling a clearly smaller spacing between the processing tracks. As a result thereof, it is also possible to employ a shared protective mechanism to prevent contamination of the optics.

Another example for the application of the inventive laser beam source wherein the material is preferably arranged in a plane derives in the semiconductor industry in the processing of what are referred to as wafers, i.e. usually circular disks of suitable semiconductor material that, for example, are incised or cut or can be provided with all conceivable patterns in the surface, of a

type that could previously be manufactured only by time-consuming chemical etching processes that were also not environmentally friendly.

For the multi-channel cutting and in sizing of materials, a simplified embodiment of the laser radiation source is inventively possible, as disclosed in the German Patent Application P 198 40 936.2 of the assignee, "Anordnung zum mehrkanaligen Schneiden und Ritzen von Materialien mittels Laserstrahlen".

A further inventive application of the laser radiation source is established in the manufacture of monitors and displays. For example, the apertured masks for color picture screens as well as the masks of what are referred to as flat picture screens or LCD displays can be manufactured in a more environmentally friendly way with laser processing than with the chemical etching processes that were previously employed, in that the inventive laser radiation source is applied.

A considerable advantage of the inventive laser radiation source is that it has a small volume and has a flexible connection, namely the laser fibers or fibers connected thereto between the pump source and the exit of the radiation at the processing location and thus allows all conceivable operating positions of the laser radiation source or of its beam exit. There are therefore also no limitations for the spatial arrangement of the processing surface, since they can be arranged in an arbitrary attitude in space.

Another advantage of the invention is comprised therein that the radiation beam of the individual lasers with defined values in beam diameter, beam divergence centering and angular direction can be exactly and durably acquired in a terminating section (terminator), as a result whereof a fabrication-suited and service-suited arrangement for forwarding the laser radiation onto the processing surface can be created. Inventively, the radiation beams can thereby be coupled into the fiber dependent on the application, for example as pump spot and/or can be coupled out as parallel laser beam, can diverge at the exit location or, for example, can be focused in a certain distance from the exit point. There is thus a desire to fashion the terminator as small as possible and to provide it with one or

more fits as a reference surface or reference surfaces for the alignment of the laser beam.

According to the invention, this is achieved in that the optical fibers are set in the terminator and the position of the optical fibers and/or the position of the emerging radiation beam is exactly adjusted. On the basis of the exact adjustment and of an inventive, correspondingly spatially small embodiment of the terminators which can also be attached to one another in an especially simple way as a result of a special shaping, it becomes possible to combine the radiation beams of a plurality of fiber lasers and focus them such that the respectively encountered object is achieved and, at the same time, an economical manufacture as well as a cost-beneficial maintenance of the laser radiation source is enabled.

The invention is explained in greater detail below on the basis of Figures 1 through 44a.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic illustration of the laser radiation source;

Fig. 2 is a fundamental illustration of the fiber laser (prior art);

Fig. 2a is an attenuated illustration of the fiber of the fiber laser (prior art);

Fig. 3 is a cross-section through an arrangement for processing material with a laser radiation source of the invention;

Fig. 4 is an illustration of a laser gun for the inventive laser radiation source having a multiple arrangement of fiber lasers;

Fig. 4a is a perspective illustration relating to Fig. 4;

Fig. 4b is a version of Fig. 4;

Fig. 4c is a further version of Figs. 4 and 4b;

Fig. 5 is an example of a terminator for the outfeed of the radiation from a fiber or, respectively, from the [fibers] fiber of a fiber laser;

Fig. 5a is an example of a multiple arrangement for a plurality of terminators;

Fig. 5b is an example of a terminator having adjustment screws;

Fig. 5c is a cross-section through the terminator according to Fig. 5b in the region of the adjustment screws;

Fig. 6 is an example of a terminator having spherical adjustment elements;

Fig. 6a is a cross-section through the terminator according to Fig. 6 in the region of the spherical adjustment elements;

Fig. 7 is an example of an embodiment of a terminator having a conical fit for insertion into a mount;

Fig. 8 is an example of a multiple mount for a plurality of terminators;

Fig. 8a shows the rear fastening of the terminators according to Fig. 8;

Fig. 9 is an example of an embodiment having quadratic cross-section;

Fig. 9a is a cross-section through the terminator according to Fig. 9;

Fig. 10 is an example of a terminator having rectangular cross-section and a trapezoidal plan view;

Fig. 10a is a longitudinal section through the terminator according to Fig. 10;

Fig. 10b is a cross-section through the terminator according to Fig. 10;

Fig. 11 is an example of a terminator having trapezoidal cross-section;

Fig. 11a is an example of a terminator having triangular cross-section;

Fig. 12 is an example of a terminator having honeycomb-shaped cross-section;

Fig. 13 is a modular implementation of the fibers of the fiber laser according to Fig. 1;

Fig. 14 is an example of the infeed of the pump energy into the fibers of the fiber laser according to Fig. 13;

Fig. 15 is an example of a fiber laser having two outputs;

Fig. 16 is an example of the merging of two fiber lasers;

Fig. 17 is a schematic illustration of the beam path through an acousto-optical deflector or, respectively, [modulators] modulator;

Fig. 18 shows blanking out unwanted sub-beams of an acousto-optical

deflector or, respectively, [modulators] <u>modulator;</u>

Fig. 18a is an arrangement having an electro-optical modulator ;

Fig. 19 is a plan view onto a four-channel acousto-optical modulator;

Fig. 19a is a section through the modulator according to Fig. 19;

Fig. 20 is a schematic beam path for a plan view for Fig. 4;

Fig. 21 is a schematic beam path for a plan view for Fig. 4b;

Fig. 22 is a schematic beam path for a plan view for Fig. 4c;

Fig. 23 shows a beam path for terminators that are arranged at an angle relative to one another;

Fig. 24 is a version of Fig. 23 that contains a multi-channel acousto-optical modulator;

Fig. 24a is a version for Fig. 24;

Fig. 25 is an intermediate [image] <u>imager</u> for matching the fiber lasers or, respectively, their terminators to, for example, the modulator;

Fig. 26 shows the merging of twice [for] <u>four</u> tracks of the beam path from terminators with a strip mirror arrangement;

Fig. 26a is a plan view for Fig. 26;

Fig. 27 is a view of a strip mirror;

Fig. 27a is a sectional drawing through the strip mirror according to Fig. 27;

Fig. 27b is another example of a strip mirror;

Fig. 28 shows the combining of twice [for] <u>four</u> tracks of the [ray] beam <u>bundle</u> from terminators with a wavelength-dependent mirror;

Fig. 28a is a plan view of Fig. 28;

Fig. 29 is an arrangement of a plurality of terminators in a plurality of tracks and in a plurality of planes;

Fig. 30 is an arrangement of a plurality of terminators in a bundle;

Fig. 31 is a sectional view through the [ray] beam bundle from the terminators of the fiber lasers F1 through F3 according to Fig. 29 or Fig. 30;

Fig. 32 is an arrangement having a plurality of terminators in a plurality of tracks and a plurality of levels having a cylindrical optics for matching, for example, to the modulator;

Fig. 33 is a modification of Fig. 32;

Fig. 34 shows a mouthpiece for the laser gun with connections for compressed air and for extracting the material released by the beam;

Fig. 35 shows a turning of the laser gun for setting the track spacings;

Fig. 36 is an illustration for generating four tracks with an acousto-optical multiple deflector or multiple modulator;

Fig. 36a is a spatial presentation of an acousto-optical multiple deflector or multiple modulators;

Fig. 36b is an expanded embodiment related to Fig. 36a;

Fig. 36c is a plan view of Fig. 36b;

Fig. 37 is an illustration for generating multiple tracks with the assistance of an acousto-optical multiple deflector or multiple modulator;

Fig. 38 is an advantageous arrangement for avoiding reflections back into the lasers;

Fig. 39 shows a lens that has coolant flowing around it;

Fig. 39a is a section through a mount [4] for an objective lens;

Fig. 40 shows a fiber laser or a fiber that have been clearly reduced in cross-section at their exit end;

Fig. 40a is a plan view onto the end of the fiber laser or the fiber according to Fig. 40;

Fig. 40b is a side view of the fiber end wherein the axes of the emerging [ray beams] beam bundles proceed nearly parallel;

Fig. 40c is a side view of the fiber end wherein the axes of the emerging [ray] beam bundles overlap outside the fiber bundle;

Fig. 40d is a side view of the fiber end wherein the axes of the emerging [ray beams] <u>beam bundles</u> overlap within the fiber bundle;

Fig. 41 shows an arrangement of fiber lasers or fibers according to Fig. 40 in a plurality of tracks and levels;

Fig. 42 shows a further embodiment of the laser radiation source;

Fig. 42a shows a further embodiment according to Fig. 42;

Fig. 42b is a sectional view of Fig. 42a;

Fig. 42c is an illustration of a robot;

Fig. 43 shows a flat bed arrangement having the inventive laser beam source;

Fig. 43a is an addition to Fig. 43;

Fig. 43b is a sectional drawing through an arrangement for removing the material released during the processing;

Fig. 44 is a hollow bed arrangement having the inventive laser beam source; and

Fig. 44a shows an addition to Fig. 44.

DESCRIPTION OF THE PREFERRED EMBODIMENT

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the preferred embodiment illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is [there3by] <u>thereby</u> intended, such alterations and further modifications in the illustrated device, and such further applications of the principles of the invention as illustrated therein being contemplated as would normally occur to one skilled in the art to which the invention relates.

Fig. 1 shows a laser radiation source 1 that is composed of a plurality of diode-pumped fiber lasers 2, also called fiber lasers, inventively implemented preferably as modules, these being charged with electrical energy by a preferably modular supply 32 that is largely converted into laser radiation. Further, a controller 33 is provided via which the modulation of the radiation is undertaken

and that [sees] provides to the interaction of the laser radiation source with its periphery. The output rays of the laser enter into an optical unit 8 at the radiation entry 9 and emerge from the optical unit at the radiation exit 10. The job of the optical unit 8 is to shape the laser radiation to form a processing spot 24 on a processing surface 81; however, the laser radiation can also be directly directed on to the processing surface without the optical unit.

Figs. 2 and 2a show the fundamental structure of a fiber laser arrangement 2. In Fig. 2, the energy of a pump source such as, for example, a laser diode, called a pump source 18 here, is shaped via an infeed optics 3 to form a suitable pump spot 4 and is coupled in to the laser fiber 5. Such pump sources are disclosed, for example, in German Patent Application P 196 03 704 of the assignee. Typical pump cross-sections of the laser fibers lie approximately between 100 μm and 600 μm in diameter given a numerical aperture of approximately 0.4. The laser fiber 5 is provided with an infeed mirror 7 at the infeed side 6 that allows the pump radiation to pass unimpeded but which exhibits 100% reflection for the laser radiation. The infeed mirror 7 can be secured to the fiber end with a suitable mount or by gluing; however, it can also be realized on the fiber end by direct vapor-deposition of a suitable layer as employed given infeed mirrors for lasers. An outfeed mirror 12 that is partially reflective for the laser radiation is attached to the outfeed side 11 of the laser fiber 5, the laser radiation 13 being coupled out through the outfeed mirror 12. Advantageously, the outfeed mirror exhibits 100% reflection for the pump radiation. As a result thereof, the remaining pump radiation is reflected back into the optical fiber, which is advantageous since the pump energy is utilized better and, further, does not represent a disturbing factor in the application of the laser radiation. The outfeed mirror can, like the infeed mirror, likewise be produced by vapor-deposition.

The infeed event of the pump radiation into the pump cross-section 14 of the laser fiber 5 is shown in greater detail in Fig. 2a. The energy in the pump spot 4 excites the laser radiation in the core 15 of the laser fiber 5 on its way through

the fiber. The pump core 16 is surrounded by a cladding 17. The core of the laser fiber that is approximately 5 μm through 10 μm thick is doped mainly with rare earths.

The relatively large pump cross-section 14 simplifies the infeed of the pump energy and enables the use of a connection between pump source and laser fiber that is simple to release, as shown in Figs. 13 and 14. The terminator of the laser fiber at the side of the pump source can thereby be advantageously structurally the same as the terminator at the outfeed side; however, it need not be. A precise [blood] plug-type connection between pump source and laser fiber offers considerable advantages in the manufacture of the fiber laser and in case of service. The laser fiber, however, can also be firmly connected to the pump source to form a laser module. As a result of the intentionally manufactured, extremely small fiber core diameter, the fiber laser supplies a practically diffraction-limited laser radiation 13 at the exit.

Fig. 3 shows a cross-section through one of the inventive embodiments of an arrangement for processing materials with the inventive laser radiation source 1. A drum 22 is rotatably seated in a housing 21 and is placed into rotation by a drive (not shown). A laser gun 23, which is conducted along the drum in the axial direction with a carriage (not shown), is located on a prism (likewise not shown).

The laser radiation emerging from the laser gun 23 impinges the surface of the drum at the processing location in the processing spot 24. Either the surface of the drum as well as a material clamped onto the drum surface can be processed. The fiber lasers, whose laser fibers 5 are respectively wound to a form, for example, an air-permeated coil 25, are supplied into the laser gun 23 with the inventive terminators 26, 94. Advantageously, however, passive single-mode fibers or other passive optical fibers, referred to in brief as fibers 28, can also be welded to the fiber lasers or coupled thereto in some other way before the terminators 26, 94 are attached, as described in Figs. 15 and 16.

The pump sources 18 of the fiber lasers are attached on a cooling member 27 that diverts the waste heat via a cooling system 31. The cooling system 31 can

be a matter of a heat exchanger that delivers the waste heat to the surrounding air; however, it can also be a matter of a cooling unit. The laser gun 23 can also be connected to the cooling system, but this is not shown. The driver electronics for the pump sources 18, which belong to the supply 32 (not shown in further detail), are preferably situated on the cooling member. A machine control is provided for the drives but is not shown in Fig. 3. The structure of the pump sources, fiber laser and corresponding power electronics is preferably modularly implemented, so that corresponding pump sources and power modules of the driver electronics that are separate or combined into groups belong to the individual fiber lasers, these being capable of being connected to one another via a bus system. As explained in greater detail in Fig. 13 and Fig. 14, the laser fibers 5 and the pump sources 18 can be connected to one another via a releasable connection. It is also possible to couple a slight part of the pump radiation out of the laser fiber 5, for example as a result of a slight injury to the cladding 14, and to conduct this via an optical fiber onto a measuring cell in order to offer a signal therefrom that can be employed for the control or, respectively, regulation of the pump radiation.

The modulation signals for the laser radiation are generated in the controller 33 and the interaction of the laser radiation source with the machine control and with the supply 32 as well as the executive sequence of the calibration events as well as of the control and regulation events are managed in the controller 33. A safety circuit (not shown), for example, switches the pump sources permanently off when there is danger.

Although a horizontally seated drum is shown in Fig. 3, the drum [being] can be arranged in any arbitrary attitude since the inventive laser radiation source is completely directionally insensitive in terms of its attitude and is very compact in terms of structure and, moreover, since the laser fibers 5 of the fiber laser or fibers 28 coupled to the laser fibers can be arbitrarily laid; for example, the shaft of the drum can also be seated vertically or inclined from the perpendicular, which yields an especially small floor space. As a result thereof, moreover, the operation of a plurality of arrangements or a system having a plurality of drums is

possible on the same floor space as would be required by an arrangement having a horizontally seated drum. As a result thereof, the printing forms can be manufactured faster; in particular, all printing forms for a color set can be produced in a single, parallel pass, which is advantageous especially with respect to the uniformity of the final result. Further, an automatic charging with printing forms for provision with images can be realized better given a system erected on a small floor space than given a spatially larger system. One or more laser radiation sources and, additionally, one or more further lasers can be directed onto the same printing form in order to accelerate the production thereof. One advantage of the multi-track arrangement having the very fine and precise tracks is that potential seams are clearly less disturbing then when recording is carried out with coarser tracks. As described under Fig. 37, further, the position of the tracks can be precisely re-adjusted, so that residual errors become clearly smaller than a track width. The inventive laser radiation sources can thereby be preferably utilized for processing the finer contours and the further laser or lasers can be utilized for processing rougher contours, which can be particularly employed given printing forms that, for example, are composed of plastic or rubber.

Instead of one or each of the provided fiber lasers 2, it is conceivable to provide a laser system with a terminator into the laser radiation source and alternative supply to the laser gun 23, whereby the fiber laser described in detail under Fig. 2, however, represents the more cost-beneficial solution. When processing materials, namely, if the radiant power of a plurality of lasers that are not coupled to one another and that naturally emit with a slight wavelength difference are directed onto a processing spot, a phase equality of the individual lasers can be foregone and an expensive control and regulation technology for a phase coupling that is susceptible to malfunction can be avoided.

Such a laser system that, for example, is disclosed by US-A-5,694,408 contains an optical post-amplification and comprises a radiation output composed of a fiber. A terminator is described in greater detail later in one of the Figures 5, 5a, 5b, 5c, 6, 6a, 7, 9, 9a, 10, 10a, 10b, 11, 11a or 12.

Instead of employing the laser system disclosed by US-A-5,694,408, it is also conceivable to employ a phase-coupled laser system according to US-A-5,084,882. An image of the fiber bundle then results on the processing surface as the respective processing spot. Alternatively, a single-mode fiber could be welded to each fiber at the exit of the bundle, this being provided with the respective terminators, and supply the laser gun. However, it is extremely difficult and complicated to manufacture such phase-coupled laser systems and they would be correspondingly expensive. Up to now, such phase-coupled laser systems have also not been commercially available.

Fig. 4 is a section through an applied example of a laser gun having sixteen fiber lasers that are coupled via terminators 26 and having a modulation unit composed of two multi-channel acousto-optical modulators 34. The laser gun is a multi-part receptacle for the adaptation of the optical unit and contains mounts 29 (Fig. 4a) with fitting surfaces for the fits of the terminators 26, means for combining the individual laser beams, the modulation unit, a transmission unit for the transmission of the laser radiation that is intended to produce a processing effect onto the processing surface, and an arrangement for neutralizing the laser radiation that is not intended to produce a processing effect. An arrangement for removing the material eroded from the processing surface can be arranged at the laser gun; this, however, can also be arranged in the proximity of the processing surface in some other way.

Fig. 4a shows a perspective illustration relating to Fig. 4.

Fig. 4b shows a modification of Fig. 4 wherein the [ray beams] <u>beam bundle</u> of the individual fiber lasers do not proceed parallel as in Fig. 4 but at an angle relative to one another; this, however, cannot be seen from the sectional view in Fig. 4b and is therefore explained in greater detail in Figs. 21, 22 and 24.

Fig. 4c shows a modification of Fig.4b that enables an advantageous, significantly more compact structure as a result of a differently implemented transmission unit.

Fig. 4 shall be explained in detail first with the assistance of Fig. 4a. These explanations apply analogously to Figs. 4b and 4c.

In a housing 35, 4 fiber lasers F_{HD1} through F_{HD4}, F_{VD1} through F_{VD4}, F_{HR1} through F_{HR4}, F_{VR1} through F_{VR4} via terminators 26 with mounts 29 (Fig. 4a) are arranged in respectively four tracks of one beam packet [H], being arranged side-by-side in a plane. The embodiment of the terminators 26 employed in Fig. 4 is described in greater detail in Fig. 9. The terminators should preferably be inserted gas-tight into the housing 35, to which end seals 36 (Fig. 4a) can be employed. Instead of the terminators shown in Figs. 4 and 4a, differently shaped terminators can also be employed, as described in Figs. 5, 5a, 5b, 5c, 6, 6a, 7, 9, 9a, 10, 10a, 10b, 11, 11a and 12, when corresponding mounts 29 are provided in the housing 35. However, as also described under Fig. 3, single-mode fibers or other fibers 28 can be attached to the fiber lasers before the terminators 26 are attached. However, an arrangement of the laser fibers 5 or fibers 28 according to Figs. 40, 40a, 40b, 40c, 40d and 41 can also be employed. For example, the fiber lasers F_{HD1} through F_{HD4} or, respectively, F_{VR1} through F_{VR4} should have a different wavelength than the fiber lasers F_{VD1} through F_{VD4} or, respectively, F_{HR1} through F_{HR4}. For example, F_{HD1} through F_{HD4} and F_{VR1} through F_{VR4} should have a wavelength of 1100 nm whereas F_{VD1} through F_{VD4} or, respectively, F_{HR1} through F_{HR4} should have a wavelength of 1060 nm, which can be achieved by a corresponding doping of the laser-active core material of the laser fibers 5. However, all fiber lasers can also exhibit different wavelengths when they are correspondingly compiled.

As explained in greater detail in Figs. 28 and 28a, the beam packets of the fiber lasers F_{HD1} through F_{HD4} are united with those of the fiber lasers F_{VD1} through F_{VD4} and the beam packets of the fiber lasers F_{VR1} through F_{VR4} are united with those of the fiber lasers F_{HR1} through F_{HR4} to form a respective beam packet F_{D1} through F_{D4} as well as F_{R1} through F_{R4} (Fig. 4a) via wavelength-dependent mirrors 37 as means for the combining. There are also other possibilities of influencing the wavelength of the fiber lasers; for example, wavelength-selecting elements

such as Brewster plates, diffraction gratings or narrowband filters can be introduced in the region of the laser fibers between infeed mirror 7 and outfeed mirror 12. It is also possible to provide at least one of the two laser mirrors 7 or 12 with a mirror layer of a type that is adequately highly reflective only for the desired wavelength. The inventive execution of the beam merging, however, is not limited to the employment of fiber lasers with different wavelengths. In addition to fiber lasers that have no privileged direction in the polarization of the laser emission that is output, fiber lasers can also be employed that output a polarized laser emission. When the wavelength-dependent mirror is replaced by a mirror that is polarization-dependent such that it allows one polarization direction to pass whereas it reflects the other polarization direction, only two differently polarized laser types need be employed in order to unite the two with the polarization-dependent mirror. In this case, the employment of the terminator 26 according to Fig. 9 having a quadratic cross-section is especially suitable, since the one or the other polarization direction can be respectively produced with the same fiber laser by turning the terminator by 90° before being mounted into the housing 35.

A particular advantage of the combining of a plurality of lasers to form a single spot, namely to each of the individual processing points B_1 through B_n (for example B_1 through B_4 in Figs. 20 through 22) is that a higher power density is achieved given a predetermined spot size on the processing surface 81.

The laser emission of the individual fiber laser can also be distributed onto a plurality of terminators, this being described in Fig. 15. This is particularly useful when materials are to be processed that manage with a low laser power or when the power of an individual fiber laser is adequately high. In such a case, it is conceivable that a laser gun 23 is equipped with only four terminators, for example F_{HD1} through F_{HD4}, for this purpose, F_{HD1} and F_{HD2} thereof, for example, being supplied by one fiber laser and F_{HD3} and F_{HD4} being supplied by a further fiber laser according to Fig. 15. When the principle described in Fig. 15 is applied twice, all four tracks F_{HD1} through F_{HD4} can be supplied by one fiber laser,

this leading to an extremely cost-beneficial arrangement, particularly since further component parts such as wavelength-dependent mirrors and strip mirrors can be eliminated and, thus, an especially economical embodiment of the laser radiation source can be created.

By omitting fiber lasers or, respectively, tracks, further, the acquisition costs for such an arrangement can be lowered as needed and fiber lasers can be retrofitted later as needed. For example, one can begin with one fiber laser and one track. The lacking terminators of the fiber lasers that are not introduced are replaced for this purpose by structurally identical terminators that, however, do not contain a through opening and no laser fibers and only serve for termination in order to close the housing 35 as though it were equipped with all terminators.

However, the laser radiation of a plurality of fiber lasers can also be combined and conducted into a single terminator, this being described in Fig. 16. For example, one can work with a plurality of fiber lasers combined in this way and with one track when, as described, the missing terminators are replaced by structurally identical terminators that, however, do not contain a through opening and no laser fibers in order to close the housing 35 as though it were equipped with all terminators.

Immediately after the [ray] beam <u>bundle</u> has left the respective terminator, a part of the laser emission can be coupled out via a beam splitter (which, however, is not shown) and can be conducted onto a measuring cell that is not shown in the Figs. in order to produce a measured quantity therefrom that can be used as comparison value for a control of the output power of each and every fiber laser. However, laser emission can also already be coupled out of the laser fiber for the acquisition of a measured quantity before the terminator, this also not being shown.

The plurality of planes wherein the terminators are arranged is not limited to the one plane as described. For example, arrangements having three planes are recited in Figs. 29, 32, 33 and 41. An arrangement having two planes is shown in Fig. 38.

The respective beam packets of the fiber lasers are modulated via a respective four-channel acousto-optical modulator 34 whose functioning and embodiment is explained in greater detail in Figs. 17, 18, 19 and 19a. Using the acousto-optical modulator 34, which is a deflector in terms of principle, the unwanted energy in the case illustrated here is deflected out of the original beam direction I_0 into the beam direction I_1 (Fig.4a), so that it can be simply intercepted later in the beam path and neutralized. The modulation can preferably occur digitally, i.e. a distinction is made between only two conditions in the individual modulator channels, namely "on" and "off", this being especially simple to control; however, it can also occur in analog fashion since the laser power in each modulator channel can be set to arbitrary values. The modulation is not limited thereto that the energy from the beam direction I_0 is employed for the processing and the energy from the direction I_1 is neutralized. Figs. 36, 36a, 36b, 36c and 37 recite examples wherein the beam direction 1_1 that is diffracted off is employed for processing and the energy from the direction I_0 is neutralized. Further, a slight part of the modulated radiant power of the individual modulator channels can be [forward] <u>forwarded</u> onto a respective measuring cell via a beam splitter (not shown) in order to generate a measured quantity that is used as a comparison value in a control circuit for the exact regulation of the laser energy of each track on the processing surface.

The multi-channel acousto-optical modulator 34 is preferably secured on a cylindrical modulator housing 41 that is rotatably seated in an opening 48 in the housing 35. After the modulator housing has been adjusted to the required Bragg angle α_B, the modulator housing is fixed with a connection 42. A seal 43 sees to it that each modulator housing terminates gas-tight relative to the housing 35. A specifically prepared printed circuit board 171 projects from the modulator housing 41 into the interior space 44 of the housing 35, electrical connections to the piezo-electric transducers 45 being produced thereover. The preferred embodiment of the modulators is described in greater detail in Figs. 19 and 19a.

After passing through the acousto-optical modulators, the beam packets F_{D1} through F_{D4} and F_{R1} through F_{R4} are conducted to a strip mirror 46 that is described in greater detail in Figs. 26, 26a, 27, 27a and 27b. The beam [packets] packet F_{D1} through F_{D4} is arranged with respect to the strip mirror 46 such that it can pass through the strip mirror unimpeded. The laser beam bundles of the beam packet F_{R1} through F_{R4}, however, are offset by half a track spacing compared to the beam packet F_{D1} through F_{D4} and impinge the strips of the strip mirror arranged in strip-shaped fashion. As a result thereof, they are redirected in terms of their direction and now lie in one plane with the laser beam bundles F_{D1} through F_{D4}. An eight-track arrangement thus derives, whereby two lasers of different wavelengths are also superimposed in each track, so that a total of sixteen lasers have been merged and take effect. [Two] The beams I_1 that have been diffracted off in the acousto-optical modulator 34 are located above this plane I_0. Given a different adjustment of the acousto-optical modulator 34, the rays that are diffracted off can also lie under the plane of I_0, as shown in Figs. 4b and 4c.

A significant advantage of the inventive arrangement is that the symmetry axis of the beam packets F_{HD1} through F_{HD4} and F_{D1} through F_{D4} lie on the axis of the housing 35 that is defined by the bore 47, and the beam axes of the corresponding beam packets respectively lie parallel or at a right angle to this axis, which allows a simple and precise manufacture. However, it is also possible to arrange the beam packets asymmetrically and at different angles. Further, it is possible to correct small differences in the position of the beam packets by adjusting the wavelength-dependent mirrors 37 and of the strip mirror 46. It is possible to still re-adjust the terminators in position after they are mounted and in terms of their angular allocation, for example for individual optimization of the Bragg angles in the individual channels; this, however, is not shown in the Figures.

It lies within the scope of the invention that the plurality of tracks is reduced but can also be increased further; for example, by joining respectively

eight instead of four terminators that are connected to fiber lasers to form a beam packet, a doubling of the number of tracks can be undertaken. For this purpose, two eight-channel acousto-optical modulators would have to be utilized. Acousto-optical modulators having 128 separate channels on a crystal can be commercially obtained.

Within the framework of the invention, it is likewise possible to arrange the fiber lasers in different planes for increasing the power per track and to superimpose their power on the processing surface, this being explained in greater detail in Figs. 29, 31, 32, 33 and 41 and/or to arrange a plurality of fiber lasers in bundles in order to superimpose their energy on the processing surface, this being described in Figs. 30 and 31.

Another possibility for increasing the number of tracks is described in Fig. 37.

Directly modulatable fiber lasers can also be utilized, this being described in greater detail in Fig. 23. In this case, the acousto-optical modulators are omitted and an especially simple structure derives.

Operation with a plurality of tracks of lasers and a plurality of lasers in a track enables high processing speeds given low relative speed between the laser gun and the workpiece. The processing speed can also thus be optimally adapted to the time constant of the heat [elimination] <u>absorption</u> of the material. Given a longer operating time, too much energy uselessly flows off into the environment.

The housing 35 is closed gas-tight with a cover and a seal, neither being shown in the Figures. A cylindrical tube 51 is flanged to the housing 35 in the region of the bore 47 and is sealed via a seal 52. The cylindrical tube contains as an optical transmission unit two tubes 53 and 54 each having a respective optical imaging system that image eight laser beam bundles F_{D1} through F_{D4} and F_{R1} through F_{R4} at the [beam] <u>radiation</u> exit 10 (Fig. 1) onto the processing surface in the correct scale. Two optical imaging systems are preferably arranged following one another, since an extremely great structural length or a very small distance between the objective lens and the processing surface would otherwise derive,

both being disadvantageous since a long beam path must be folded with mirrors and too small a spacing between objective lens and processing surface could lead to a high risk of contamination for the objective lens.

The beam path is shown as a side view in Fig. 4. The fundamental beam path is shown in Fig. 20 as a plan view for the beam packet F_{HD1} through F_{HD4}. The wavelength-dependent mirrors, the modulators and the strip mirrors are not shown therein. The Figures mainly show plano-convex lenses; however, it is also possible to utilize other lens forms such as, for example, biconvex or concave-convex lenses or lenses having an aspherical shape in all figures. Lens systems that are respectively composed of a plurality of lens combinations can also be employed.

In order to transmit the laser energy as efficiently as possible and keep the heating of the optical components within limits, all optical surfaces occurring in the various embodiments of the laser radiation source are anti-[bloomed] reflection coated with outmost quality for the wavelength range coming into consideration. The optical imaging systems can preferably be telecentrically implemented.

There are also other advantageous solutions for the transmission unit in order to shorten the structural length of the transmission unit and thereby nonetheless achieve a large spacing between the objective lens and the processing surface, as is shown in even greater detail in, among others, Figures 4b and 4c. The lenses 55 and 56 can be connected to the tube 53 by screwed connections or by gluing; however, they can also be preferably metallized at their edges and soldered to the tube 53. The same is true of the lenses 57 and 61 in the tube 54. A gas-tight seal of the lenses and a good heat transmission from the lenses to the tubes thus derives. The tube 54 is preferably terminated gas-tight relative to the cylindrical tube 51 with a seal 62. With respect to tightness and cleanliness, the same conditions apply to the space 63 as apply to the space 44 and, likewise, to the spaces 64 and 65 within the tubes 53 and 54. The chambers 66 and 67 are

preferably connected to the spaces 44 and 63 via bores 71. The tubes 53 and 54 can preferably comprise openings 72.

An intercept arrangement 73 for neutralizing the laser radiation that is not intended to produce any processing effect on the processing surface and that comprises a high-reflectivity mirror 74 and a dispersion lens (concave lens) 75 projects into the space 63. The principle of the intercept arrangement 73 is described in greater detail in Fig. 18. The intercept arrangement 73 is introduced with a seal 76, and the concave lens 75, which can also be replaced by some other optical element, for example a glass plate, is glued into the intercept arrangement or is preferably metallized at an image edge zone and soldered to the intercept arrangement for better heat elimination. The space 63 is thus closed off gas-tight from the environment. What derives as a result of the described techniques is that the entire interior of the laser gun is sealed gas-tight from the environment. The spaces 44, 63, 64 and 65 and the chambers 66 and 67, i.e. the entire interior of the laser gun, can be preferably evacuated or filled with a protective atmosphere. The spaces and chambers should be as free as possible of components that output gases or particles because dirt could otherwise settle on the highly stressed optical surfaces, which would lead to a premature failure of the arrangement. The seals to be employed should not give off any particles or gases. Ultimate cleanliness of the parts to be assembled and of the environment has great value associated with it during assembly until the laser gun has been closed. After the closing of the laser gun 23, an evacuation of the entire interior can be undertaken via the valve 77 or a protective atmosphere can be filled in. The advantage of filling the interior with protective atmosphere is that it is simpler to replenish in that a gas bottle (not shown) is connected to the valve 77 during operation via a pressure-[producing] reducing valve, gas being capable of being refilled into the housing therefrom as needed. Another advantage is that, when a terminator is to be removed from the housing for the replacement of a fiber laser and is to be replaced by another or when the housing or, respectively, the cylindrical tube must be opened by the user for some reason or other, a slight quantity of the protective

atmosphere can be allowed to flow through the housing during the procedure in order to thus prevent the penetration of dirt particles into the protected space. A slight quantity of the gas can also be allowed to constantly flow through the housing and escape such through openings, preferably in the proximity of the objective lens. This flow also prevents a contamination of the objective lens by dirt particles that are released during the processing event (Fig. 39a). The evacuation or the filling with protective atmosphere can also be foregone when a shorter service life of the laser radiation source is accepted.

It is advantageous in the arrangement according to Fig. 4 that the angle between the beam packets of the original beam direction I_0 of the acousto-optical modulator and the beam direction I_1 that is diffracted off is noticeably increased by the imaging system composed of the lenses 55 and 56, so that it is simple to intercept the unwanted radiation packet of the deflected beam direction with the highly reflective mirror 74 at the intercept arrangement 73. The mirror 74 is preferably fabricated of metal and is provided with a highly reflective layer in order to keep the heating as a consequence of absorbed laser energy low. For better heat elimination, it is connected via a strong flange of the intercept arrangement 73 to the tube 51. However, the intercept arrangement can also be foregone when the highly reflective mirror is replaced with an optical component such as, for example, a lens that slightly modifies the optical properties of the laser radiation to be intercepted such that the focus of the radiation that is diffracted off is different from the focus of the radiation employed for processing the material. If the radiation to be intercepted would then also be conducted onto the processing surface, the radiation to be intercepted would not have the required power density in order to erode material but would be uselessly absorbed and reflected. The advantage of the arrangement according to Fig. 4 is that low demands are made of the optical components in the two tubes. The two tubes could also be implemented completely the same. Another advantage is that the axes of the terminators 26 lie parallel to one another. The distance between the objective lens 61 and the processing surface 81 dare not be too small, so that

particles that fly off from the material surface do not proceed onto the objective lens. When it is contaminated, it then absorbs the laser energy that passes, is destroyed, and is thus unuseable. In order to prevent the contamination, a special mouthpiece 82 is arranged between the objective lens 61 and the processing surface 81, this being described in greater detail under Fig. 34.

The laser gun 23 of the laser radiation source is rotatable around the optical axis that is identical to the axis of the cylindrical tube 51, 95 within the arrangement for processing materials (Fig. 3), for example on a prism 83, and is seated displaceable in the direction of the optical axis and fixed in its position with a strap retainer 85 or with a plurality of strap retainers. As a result thereof, an exact [delivery] <u>adjustment</u> of the laser gun to the processing surface 81 is possible. A plate 86 that comprises openings 87 through which a coolant can be pumped is located outside the prism 83. The job of this plate 86 is to intercept and divert the laser energy intercepted from the beam path of the transmission unit, this being shown in greater detail in Fig. 18. A heat dam that, however, is not shown in the Figs., is located between the plate 86 and the tube 51, 95, 113. The plate is connected to the tube 51, 95, 113 via insulating flanges 91. The flanges 91 also prevent the emergence of laser radiation.

By turning the laser gun 23 around its optical axis, the track spacing of the laser tracks on the processing surface 81 can be modified, this being shown in greater detail in Fig. 35. It lies within the scope of the invention that the turning of the laser gun for setting the track spacing as well as the setting of its spacing from the processing surface can be implemented not only exclusively manually but with the assistance of a suitable, preferably electronic control and/or regulation. Suitable measuring devices (not shown) can also be inventively provided for this purpose, these being located in the proximity of the processing surface and being capable of being approached by the laser gun as needed. A further possibility for adjusting the track spacing is described in Figs. 36, 36a, 36b, 36c and 37. A manually or motor-adjustable vario-focusing optics can also be utilized for setting the track spacing. Such a vario-focusing optics, in addition

to permanently arranged lenses, preferably has two movable lens [system] systems, whereby an adjustment of the first lens system mainly effects an adjustment of the imaging scale, with which the track spacing can be influenced, and whereby an adjustment of the second lens system mainly effects an adjustment of the focusing. An iterative setting can be undertaken for optimizing track spacing and best focus. It is also possible to arrange a displaceable lens (not shown) having a long focal length, preferably between the lenses 57 and 61, with which the focusing of the processing points on the processing surface can be finely readjusted without having to displace the radiation source because the resultant focal length of two lenses is dependent on their spacing.

As a result of the high laser power, the optical elements in the beam path will heat, since they absorb a part, even though a slight part, of the laser energy. Preferably, the critical optical components are therefore not made of glass but of a material having better thermal conductivity, for example of sapphire. The waste heat, given metallization of the connecting surfaces of the optical components, is eliminated by the solder connections to the mounts and to the housing. For better heat output, the housing is implemented with cooling [ribs] fins 92 that can be cooled by a ventilator (not shown). A permeation of the housing 35 as well as of the other component parts of the laser radiation source with bores is also possible, particularly in the critical regions at the lens mounts and mounts for the terminators 26, a coolant being capable of being pumped therethrough, as shown in Figs. 8 and 39.

Since, as presented above, extremely high laser powers are required in processing of materials, it is critical to the invention to keep the [plurality] number of optical elements, particularly lenses, in the beam path as low as possible in order to keep the optical losses and the risk of contamination of the optics, which would always lead to a premature failure, as low as possible. It is also lies within the scope of the invention that the objective lens (61, 103 and 112) is equipped with an interchangeable mount so that it can be quickly replaced by the user of the laser radiation source as needed, whether because it has been

contaminated during operation or because a different imaging scale is requested. In this case, it is advantageous that the bore 72 and the tube 54 is not implemented.

It also lies within the scope of the invention that techniques are undertaken in the optical beam path so that no laser energy can proceed back into the lasers. It is shown in Fig. 3 that the laser radiation impinges the material to be processed not perpendicularly but at an angle, so that the radiation reflected at the material surface cannot proceed back into the laser radiation source. It is also shown in Figs. 4, 4b, 4c and Fig. 18 that the laser radiation to be destroyed can be conducted by an obliquely placed concave lens 75 into a sump composed of an obliquely placed plate 86 that can be cooled. Instead of the concave lens of 75, some other optical component, for example a plate or a diaphragm, can also be inventively employed. The effective diameter of this optical component is thereby dimensioned such that the laser radiation conducted into the sump can just pass, whereas radiation that is reflected back from the sump or is dispersed back, is largely retained, so that no energy can proceed back into the laser. Inventively, the surface of the plate 86, which is shown as a planar surface in the Figures, can also be implemented crowned or hollow and can be preferably roughened in order to absorb a maximum of radiation and reflect or, respectively, disperse a minimum of radiation.

It is also shown for two planes in Fig. [8] <u>38</u> that, as a result of a slight parallel offset of the beam axes of the [ray beams] <u>beam bundles</u> emerging from the terminator, an oblique incidence onto all effected lens surfaces can be achieved. This also applies for the arrangement having one or more planes. The acousto-optical modulator 34 is already rotated by the angle α_B relative to the axis of the [ray] beam <u>bundle</u>; however, it can also be additionally rotated by the angle γ relative to the symmetry axis of the [ray] beam <u>bundle</u> or an arrangement according to Fig. 24 can be employed wherein the axes of the ray beams emerging from the terminators proceed at an angle relative to one another. It has been shown in practice that angular differences of 1 through 2 degrees between the

perpendicular onto the optical surface and the axis of the beam bundle are already adequate in order to achieve protection against radiation reflected back into the laser.

It lies within the scope of the invention to select embodiments of the optical, mechanical and electrical arrangement for Fig. 4 deviating from the described embodiment. For example, the [radiation] <u>beam</u> packets F_{D1} through F_{D4} and F_{R1} through F_{R4} could be focused onto the processing surface by a shared lens, similar to that shown in Fig. 31, which in fact yields a very high powered density but cannot present the shape of the processing spot as well since all processing points lie on one another and are united to form a common spot.

Fig. 4b shows another inventive laser gun for a laser radiation source that differs from the laser gun shown in Fig. 4 on the basis of a housing 93, terminators 94, a cylindrical tube 95, a tube 96 and on the basis of a highly reflective mirror 97.

The housing 93 has mounts 29 fitting the terminators 94. The terminators 94 preferably correspond to those of Figs. 10, 10a and 10b; the axes of the [ray beams] <u>beam bundles</u> do not proceed parallel in the corresponding beam packets. Rather, they proceed somewhat toward the center of the concave lens 101, which is shown in the plan view 21. However, all other terminators according to Figs. 5, 5a, 5b, 5c; 6, 6a; 7, 9, 9a; 11, 11a and 12 can also be employed when it is insured that the mounts 29 [therefor] <u>therefore</u> are arranged at a corresponding angle. The transmission unit is located in the tube 96, this transmission unit being composed of three lenses, namely a dispersion lens, i.e. a concave lens 101, and two positive lenses, i.e. convex lenses 102 and 103, whereby the convex lens 103 is preferably implemented as an interchangeable objective lens. For the mounting of the lenses with respect to tightness and heat elimination, what was stated as to Fig. 4 and Fig. 4a applies, as it does for the selection of material with respect to the heat conduction.

The tube body 96 can be evacuated in the space between the lenses 101 and 102 or can be filled with a protective atmosphere or, preferably, be connected

to the space 105 via a bore 104, said space 105 being in turn connected via a bore 106 to the space 107. The space 107 is connected to the space 111 via the bore 47, said space 111 being in turn terminated gas-tight, as described under Fig. 4 and Fig. 4a. The space between the lenses 102 and 103 can be connected via a bore (not shown) to the space 105, particularly when the mount of the objective is closed gas-tight or, as described under Fig. 4, when a slight amount of the protective atmosphere constantly flows through the laser gun and emerges in the proximity of the objective lens, this, however, not being shown in Fig. 4b. The entire interior of the laser gun, composed of the spaces 111, 105, 107, is preferably evacuated or filled with a protective atmosphere or, respectively, flooded by a protective atmosphere, as was described in detail under Fig. 4 and Fig. 4a. The undesired [ray beams] beam bundles are intercepted with a highly reflective mirror [96] 97; in contrast to Fig. 4, however, no lens system is present that has an angle-enlarging effect, so that the distance between the highly reflective mirror and the modulators is kept correspondingly large here in order to achieve an adequate spatial separation of the beam packets I_0 and I_1. Nonetheless, the entire structural length of the laser gun is similar here to the arrangement of Fig. 4. The optical beam path of the transmission unit in Fig. 4 represents a side view. Fig. 21 indicates a fundamental beam path for a plan view relating to Fig. 4b. The beam path of the lenses 101 and 102 corresponds to that of an inverted Galileo telescope; however, it can also be implemented as an inverted Kepler telescope when the concave lens 101 having a short focal length is replaced by a convex lens. Such telescopes are described in the textbook "Optik" by Klein and Furtak, Springer 1988, pages 140 through 141. The advantage of the arrangement according to Fig. 4b is that only three lenses are required for the transmission unit. The disadvantage, to wit that the ray beams of the individual terminators do not proceed parallel, is eliminated by terminators according to Figs. 10, 10a and 10b.

A lens 55 could also be employed in order to deflect the [ray] beam bundles into the desired direction, as was shown in Fig. 20. The individual laser [ray] beam bundles would then proceed parallel to one another between the

terminators 26 and the lens 55, that is arranged as in Fig. 4, and no difference from Fig. 4 derives with respect to the housing and the terminators or, respectively, their arrangement. Since, however, the lens 55 also exercises a collecting effect on the individual [ray] beam bundles in addition to the deflecting effect, the same conditions as in Fig. 21 would not arise at the location of the concave lens 101. This, however, can be compensated by a different adjustment of the spacing of the fiber 28 or, respectively, of the laser fiber 5 from the lens 133 or by a modification of the lens 133 in the terminators 26, i.e. the ray cone of the laser [ray] beam bundle from the individual terminators would be respectively set such that a sharp image respectively derives on the processing surface at the location of the points B_1 through B_n.

According to the invention, it is also possible to combine the lenses 102 and 103 to form a single, [shared] combined lens. A transmission unit having only two lenses then derives. It is also possible to arrange a displaceable lens (not shown) with a long focal length between the lenses 101 and 102, the focusing of the processing points on the processing surface being capable of being finely readjusted therewith without displacing the radiation source. A vario-focusing optics can also be employed, as was mentioned under Fig. 4.

A special mouthpiece 82 is provided at the laser gun 23 that is intended to prevent a contamination of the objective lens 112 and that is described in greater detail under Fig. 34.

Fig. 4c shows a laser gun that is even more significantly compactly implemented than that of Fig. 4 and Fig. 4a. In combination with a mirror arrangement, an objective lens 112 is employed as transmission unit and this can be interchanged for achieving different imaging scales. As already described under Fig. 4, a vario-focusing optics can also be employed. Inventively, however, an imaging can occur with the mirror arrangement by itself without additional objective lens 112.

Fig. 4c differs [form] from Fig. 4b in terms of the following points: The cylindrical tube 95 is replaced by an eccentric tube 113. The tube body 96 is

preferably replaced by a plate 114 having a concave mirror 115 and a mount 116 with an objective lens 112 and a highly anti-[bloomed] reflection coated plate 117. The intercept unit 73 is given an arced (convex) mirror 121 above the highly reflective mirror 97. The eccentric tube is connected to the housing 93 at one side. A seal 52 sees to the required tightness. The plate 114 is introduced into the eccentric tube 113, said plate 114 containing a passage for the beam packets I_0 and I_1 and carrying the concave mirror 115 whose dissipated heat can thus be diverted well to the eccentric tube. The eccentric tube has two axes that are preferably parallel to one another, namely, first the symmetry axis of the entering beam packets having the direction I_0 that are directed onto the arced mirror and, second, the axis between concave mirror and objective lens 112 that can be considered as an optical symmetry axis for the emerging laser radiation.

Inventively, the beam path is folded with the two mirrors 121 and 115. The arced mirror 121 is preferably fabricated of metal. It is intimately connected to the highly reflective mirror 97 and is preferably fabricated of one piece therewith. The convex surface of the arced mirror can be spherically or aspherically shaped. The mirror 115 is concavely shaped, i.e. a concave mirror. Its surface can be spherically shaped but is preferably aspherically shaped. It is preferably composed of metal. Metal has the advantage of good elimination of the waste heat. A considerable advantage given manufacture of metal also derives in the production of aspherical surfaces, which, in this case, can be produced by known diamond polishing lathing methods, as can also spherical and planar surfaces. As a result thereof, the highly [reflected] reflective mirror 97 and the arc mirror 121 can be manufactured of one piece and, preferably, in one work pass having the same shape of the surface and can be mirrored in common, which is particularly simple in terms of manufacture and very advantageous for the positional stability of the arced mirror. In the modulation of the laser energy with the acousto-optical modulator, it impinges either the arc mirror 121 or the highly reflective mirror 97. The waste heat that is produced remains the same in any case and the arced mirror stays at its temperature and, thus, its position, which is

very important since it is preferably implemented with a short focal length and the imaging quality of the arrangement is therefore very dependent on its exact position. In this case, the arced mirror 121 has advantageously co-assumed the function of the highly [reflected] reflective mirror 97. The highly reflective mirror 97 can, however, also have some other form of surface than the arced mirror 121 and, for example, can be a plane mirror.

The beam path is similar to that of an inverted mirror telescope [of] after Herschel that, however, contains a convex lens instead of the arced mirror and that is described in greater detail in Fig. 22. Mirror telescopes are described on page 152 in the "Lehrbuch der Experimentalphysik Band III, Optik" by Bergmann-Schäfer, 7th edition De Gruyter 1978. The arced mirror can also be replaced by a concave mirror having a short focal length. As a result thereof, the structural length would be slightly enlarged and different ray cones of the ray bundles emerging from the terminator would have to be set in order to obtain a sharp image in the image plane. The arced mirror could also be replaced by a convex lens having a short focal length. Another folded mirror would then have to be utilized in order to preserve the compact structure. The intercept [arrangements] arrangement 73 is attached gas-tight to the eccentric tube via a seal 76 the undesired laser energy, as described under Figs. 4, 4b and 18, being diverted via said intercept arrangement 73 to a cooling plate 86 with bores 87 and being neutralized. It is also possible to already intercept the undesired laser radiation from the beam packet I_1 at the location of plate 114 and neutralize it.

The space 111 in the housing 93 is connected to the cavity 123 via the bore 122. Both spaces can be evacuated, filled with a protective atmosphere, or flooded by a protective atmosphere, as already described. The mount 116 that accepts the interchangeable objective lens 112 is attached to the end of the eccentric tube 113 that resides opposite the housing 93. A seal 124 closes the cavity 123 gas-tight. The mount can also accept an anti-[bloomed] reflection coated plate 117 whose edge is preferably metallized and that is preferably soldered gas-tight to the mount. Its job is to keep the cavity 123 gas-tight when

the objective lens was removed for cleaning or when an objective lens having a different focal length is to be introduced in order to generate a different imaging scale. The space between the objective lens 112 and the highly anti-[bloomed] <u>reflection coated</u> plate 117 can also be connected to the space 123 via bore (not shown), particularly when the entire laser gun, as described under Fig. 4, constantly has a protective atmosphere flowing through it, this emerging in the proximity of the objective lens 112, which is shown in Fig. 39a. The highly anti-[bloomed] <u>reflection coated</u> plate 117, however, can also contain optical correction functions, as known for the Schmidt optics known from the literature, in order to thus improve the optical imaging quality of the arrangement. However, it is also possible to omit the highly anti-[bloomed] <u>reflection coated</u> plate, particularly when it contains no optical correction function and the objective lens was introduced gas-tight or a protective atmosphere flowing therethrough sees to it that no dirt can enter into the space 123 when the objective lens is replaced. A special mouthpiece 82 is provided at the laser gun 23, this being intended to prevent a contamination of the objective lens 112 and being described in greater detail under Fig. 34.

The eccentric tube can be provided with cooling [ribs] <u>fins</u> 92 over which a ventilator (not shown) can blow in order to eliminate the waste heat to the environment better. The laser gun is rotatably seated in a prism around the axis between concave mirror and objective lens in order, as described under Fig. 4, to make the track spacing adjustable and in order to set the correct distance from the processing surface 81. The laser gun can be fixed with a strap retainer 85.

It is possible to arrange a displaceable lens (not shown) having a long focal length between, preferably, the concave mirror 115 and the objective lens 112, the focusing of the processing points onto the processing surface being capable of being finely readjusted therewith without displacing the laser gun. However, a variable focusing optics <u>(zoom lens)</u> can also be utilized, as was described under Fig. 4. All descriptions that were provided for Figs. 4, 4a and 4b also apply analogously.

Fig. 5 shows a preferred embodiment of a terminator 26 for a fiber 28 or laser fiber 5, which is also a fiber. Plug-type connections for optical fibers for low powers are known in optical communications technology, in sensor applications and measurement technology; these, however, are not suitable for high powers because too much heating occurs, this leading to destruction. For example, such laser diode collimator systems, beam shaping optics and coupling optics are described in the catalog 1/97 of Schäfter & Kirchhoff, Celsiusweg 15, 22761 Hamburg, pages A1 through A6. However, the power of these systems is limited to 1000 mW and is thus below the demands for the desired applications in processing materials by a factor of 100 because an adequate heat elimination is not assured. Further, these systems are relatively large in diameter, so that no high packing density of the laser outputs can be achieved. Another great disadvantage is that these systems are not adequately sealed; they would get dirty very quickly and burn up due to an increased absorption of the laser radiation. Last but not least, it should also be mentioned that the precision of the mount for fibers and the lens are inadequate for the desired application. Terminators according to this patent application are therefore significantly more advantageous. Such terminators can be advantageously employed for coupling laser radiation out of a fiber 5, 28, as disclosed in the German Patent Application P 198 40 935.4 of the assignee "Abschlussstück für Lichtleitfasern".

This terminator 26 can be fundamentally used for all applications wherein the matter of concern is that the ray bundle emerging from a fiber 5, 28 be precisely coupled with a releasable connection. It is likewise possible with the assistance of this terminator to produce a precise, releasable connection of the fiber 5, 28 to the remaining optics. The terminator is composed of an oblong housing 132 that comprises a through cylindrical opening 130 extending in axial direction. The housing is preferably manufactured of prefabricated, for example drawn material that can preferably be composed of glass. The laser fiber 5 of the fiber laser is preferably stripped [of] off its cladding at its ultimate end and is preferably roughened at its outside surface, this being disclosed in German Patent

Application P 197 23 267, so that the remaining pump radiation leaves the laser fiber before the entry of the laser fiber into the terminator. The fiber 5, 28 can also be additionally surrounded by a single-layer or multi-layer protective sheath 131 that can be connected to the housing 132 of the terminator, for example with a glued connection 142. The housing 132 comprises fits 134 with which the housing can be exactly introduced in a mount 29 (Fig. 5a, Fig. 7, Fig. 8, Fig. 14). The fits can thereby extend over the entire length of the housing (Figs. 5b, 9, 10); however, it can also be attached in limited regions of the housing (Figs. 5, 6, 7). One or more seals 36 can be provided that, for example, are connected to the housing 132 with glue connections 142. The job of the seals is to enable a gas-tight connection of the terminators to the mounts 29. The housing can have a different diameter, for example a smaller diameter, in the region of the protective cladding 131 and of the seal 36 than in the region of the fits. At the end of the housing 132, the end of the fiber 28 or, respectively, of the laser fiber 5 is accepted and conducted within the housing in the opening 130. A lens 133 having a short focal length is secured to the other end of the housing 132, whereby the housing can [comprises] comprise a conical expansion 139 so as not to [impeded] imped the laser radiation 13. Means can be provided for adjusting the position of the fiber 5, 28 within the terminator in order to adjust the position of the fiber relative to the lens 133 within the terminator and with reference to the fits 134, as shown in Figs. 5b, 5c, 6, 6a, 7, 9, 9a, 10a, 10b, 11, 11a and 12. The radial position of the fiber 5, 28 can also be defined by the cylindrical opening 130, whereby the fiber is axially displaceable within the opening. The position of the lens 133 can either be adequately precisely mounted during assembly or can be axially and/or radially adjusted and fixed with suitable means (not shown) with reference to the fiber 5, 28 and to the fits 134, whereby the fiber can also be axially displaced (Fig. 5b). The adjustments are advantageously undertaken with a measuring and adjustment device. What the adjustment is intended to achieve is that the [ray] beam bundle 144 emerging from the lens 133 is brought into a predetermined axial and focus position with a defined cone relative to the fits 134.

After a fixing of the fiber 5, 28 within the housing 132 and of the lens 133 at the housing, the measuring and adjustment device is removed. Inventively, it is also possible to provide the end of the fiber 5, 28 with a suitable coating, for example a correspondingly thickly applied metallization 141, in the region of the terminator before assembly in order to further improve the durability of the adjustment. The fixing of the fiber 5, 28 within the housing 132 can occur with suitable means such as gluing, soldering or welding. An elastic compound 138 that represents an additional protection for the fiber is preferably provided at the transition between the housing 132 and the protective sheath 131. It is also inventively possible to fashion and align the lens 133 by corresponding shaping and vapor-deposition of a corresponding layer, preferably at its side facing toward the fiber end, such that it co-assumes the function of the outfeed mirror 12 for the fiber laser.

Fig. 5a shows a multiple arrangement of fiber laser outputs with the terminators from Fig. 5. Bores 150 for the acceptance of two terminators 26 for two tracks are provided in a housing 145. Further, respectively three pins 148 and 149 are attached in rows such within the housing 145 in extension of the bores that they represent a lateral limitation as mount 29 for the terminators and see to a precise guidance and alignment of the terminators. The diameters of the pins 148 are referenced d_1 and are preferably identical to one another. The diameters of the pins 149 are referenced d_2 and are preferably likewise identical to one another. If the diameters of the pins 148 were the same as the diameters of the pins 149, the axes of the ray beams of both tracks would lie parallel to one another in the plane of the drawing since the terminators 26 comprise cylindrical fits 134. In Fig. 5a, however, the diameters of the pins 149 are shown larger than the diameters of the pins 148, this resulting in the axes of the two ray beams proceeding at an angle relative to one another in the plane of the drawing. The angle between the ray beams is dependent on the diameter difference d_2 - d_1 and on the center-to-center spacing [m] <u>M</u> of the two pin rows. The terminators are conducted through the housing 145 at the underside in one plane and are conducted from above through a cover (not shown) of the housing that is secured to the housing and can close it

gas-tight with a seal (not shown). The housing 145 can be part of a receptacle for an optical unit for shaping the laser radiation. The terminators are secured to the housing 145 with clips 147 and screws (not shown), whereby the seals 36 see to a gas-tight closure. The arrangement is not limited to two tracks; further bores 150 can be provided and further pins 148 and 149 can be introduced in order to insert further terminators for further tracks. The arrangement is not limited to the one plane as described; further bores 150 can be inserted into the housing 145 in further tracks and in one or more further planes, these lying above or below the plane of the drawing, and the pins 148 and 149 are lengthened to such an extent that they represent mounts 29 for all tracks and all planes. Inventively, pins 148 and 149 are likewise employed for producing a defined spacing between the planes. In this case, the pins proceed horizontally between the terminators. For example, the horizontally arranged pins 149 proceed between the wall of the housing 145 wherein the bores 150 lie and the row of illustrated, vertically arranged pins 149. The horizontally arranged pins 148 preferably proceed at a spacing [m] M parallel to the horizontally arranged pins 149. Horizontally arranged pins are not shown in Fig. 2a. The pins 148, 149 are preferably fabricated of drawn steel wire; however, they can also be composed of other materials, for example of drawn glass. An advantage given the arrangement with a plurality of tracks and/or planes in the illustrated way is that the pins 148, 149 exhibit a certain flexibility. As a result thereof, it is possible to press the entire packet of the terminators together in the direction of the tracks and in the direction of the planes such that the terminators 26 with their fittings 134 lie against the pins without spacing, this being desirable for achieving utmost precision.

Fig. 5b shows a terminator 26, whereby means for adjusting the position of the fiber 5, 28 within the terminator are provided in order to be able to adjust the position of the fiber 5, 28 relative to the lens 133 within the terminator and with respect to the fittings 134. The position of the lens can also be adjusted. The adjustments are advantageously undertaken with an adjustment device. Adjustment screws 135, 136 (Figs. 5b, 5c, 9, 9a, 10a, 10b, 11, 11a, 12) and/or

balls 137 (Figs. 6, 6a, 7) can be provided for the adjustment of the position of the fiber 5, 28 in the housing 132. The fiber 28 or laser fiber 5 can also be axially displaced within the adjustment screws 135, 136 or balls 137. The position of the lens 133 can either be adequately precisely mounted during assembly or axially and/or radially adjusted and fixed by means (not shown) with reference to the fiber 5, 28 and with reference to the fittings 134, whereby the fiber can also be axially displaced. The adjustments are advantageously undertaken with a measuring and adjustment device. What the adjustment is intended to achieve is that the [ray] beam bundle 144 emerging from the lens 133 is brought into a predetermined axial and focus position with a defined cone on the basis of a relative [advance] adjustment of lens 133 and fiber 5, 28 toward the fits 134. After a fixing of the fiber 5, 28 within the housing 132 and of the lens 133 to the housing, the measuring and adjustment device is removed. That stated under Fig. 5 for this and the other embodiments continues to apply, for example regarding the metallization 141, the elastic compound 138 and the employment of the lens 133 as laser mirror.

Fig. 5c shows a cross-section through the terminator 26 in the region of the adjustment screws, from which it can be seen that preferably three adjustment screws 135 are provided distributed over the circumference, the fiber 28 or, respectively, the laser fiber 5 being adjustable in fine fashion in the housing therewith. Further, further adjustment screws 136, as shown in Fig. 5b, can be provided within the terminator at the end of the terminator at which the fiber 28 or, respectively, the laser fiber 5 enters. These adjustment screws are designed like the adjustment screws 135. When only one set of adjustment screws 135 is employed, the fiber 28 or the laser fiber 5 can only be adjusted with respect to the angle. When two sets of adjustment screws are employed, they can also be displaced parallel to their axis. The fixing of the fiber 5, 28 within the housing 132 can occur with suitable means such as gluing, soldering or welding.

Fig. 6 shows an embodiment of the terminator 26 wherein small balls 137 of metal or, preferably, metallized glass are employed instead of adjustment

screws, these being brought into their position in the housing and being subsequently glued or soldered. A plurality of sets of balls can also be applied.

Fig. 6a shows a cross-section through the terminator in the region of the balls 137.

In order to prevent the optical surfaces on the optical fiber and the side of the lens 133 that faces toward the optical fiber from contaminating biparticles in the ambient air, the connections in Figs. 5, 5b, 5c, 6, 6a, 7, 9, 10, 11, 11a and 12 between the lens 133 and the housing 132 as well as between the adjustment screws 135 and 136 or, respectively, the balls 37 and the housing 132 can be hermetically closed. This can occur with suitable glued or soldered connections 142. When a soldered connection is preferred, the glass parts are previously metallized at the corresponding locations 141. In order to achieve a greater strength, the glued or soldered connections can also entirely or partially fill the remaining gap between the fiber 28, the laser fiber 5 and the housing 132, or the protective sheath 131 in the proximity of the terminator, this being shown, by way of example, in Fig. 5. It is also possible to durably evacuate the interior 143 of the housing or fill it with a protective atmosphere.

Fig. 7 shows a further embodiment of a terminator 26 that is introduced in a housing 145 with a mount 29. Given this embodiment, the front, outer fitting 134 in the region of the lens 133 is conically implemented for better sealing and for better heat elimination. Additionally, a seal 146 can be provided that instead of being attached to the lens-side end of the terminator as shown, can also be attached to the fiber-side end thereof.

Fig. 8 shows mounts 29 in a housing 145 for a plurality of conically implemented terminators 26 according to Fig. 7. Such mounts are advantageous when a plurality of outputs of fibers or fiber lasers are to be arranged next to one another or next to one another and above one another. The axes of the mounts can thereby be arranged such that the axes of the [ray beams] <u>beam bundles</u> emerging from the terminators of the terminators lying side-by-side and/or above one another proceed parallel to one another or at an angle. In order to eliminate

the waste heat, the housing 145 can be inventively provided with bores through which a coolant is conducted.

Fig. 8a shows the rear fastening of the terminators 26 in the housing 145. For fixing the terminators 26, 94, clips 147 are provided that fix the ends of the terminators with screws 151 in the housing at the locations at which the fibers respectively enter into the housing of the terminators 26, 94.

Fig. 9 shows an embodiment of a terminator 26 having a quadratic or rectangular cross-section, whereby all outside surfaces lie opposite one another proceed parallel and can be fittings 134. Fig. 9a shows a cross-section through the terminator 26 according to Fig. 9 having a quadratic cross-section.

Fig. 10 shows an embodiment of the terminator 94 with rectangular cross-section, whereby two outside surfaces lying opposite one another proceed trapezoidally and two outside surfaces lying opposite one another proceed parallel to one another. The outside surfaces can be fittings 134.

Fig. 10a shows a longitudinal section and Fig. 10b a cross-section through the terminator according to Fig. 10.

Fig. 11 shows terminators 26 having trapezoidal cross-sections, so that a row of terminators arises by successive turning of the terminators by 180° when a plurality of terminators are joined to one another, whereby the center points of the terminators lie on a central line. When desired, a plurality of such rows can be arranged above one another, which is indicated with broken lines in Fig. 11.

Fig. 11a shows terminators 26 with a triangular cross-section that can likewise be arranged in a plurality of rows above one another, this being indicated with broken lines.

Fig. 12 shows terminators 26 having a hexagonal cross-section that can be arranged honeycomb-like for increasing the packing density.

The inventive terminators advantageously enable the laser radiation source to be built of individual modules.

Fig. 13 shows an applied example of the terminator 26 or 94 given a fiber 28 or a laser fiber 5 that have both ends provided with a respective, inventive terminator.

According to the invention, it is possible to preferably implement the lens 133 at its side facing toward the fiber end on the basis of a corresponding shape being and vapor-deposition of a corresponding layer such that it co-assumes the function of the outfeed mirror 12. According to the invention, it is also possible to implement the lens 3, 154 by corresponding shaping and vapor-deposition of a corresponding layer that it co-assumes the function of the infeed mirror 7.

It is fundamentally possible to combine a plurality of the terminators described above in a plurality of tracks side-by-side and above one another in a plurality of planes to form a packet.

It is also possible to implement the shape of the terminators differently from that shown in the Figures, for example that a cylindrical shape according to Fig. 6 is lent trapezoidal or rectangular fits according to Fig. 9 or Fig. 10.

Fig. 14 shows a coupling of the laser fiber 5 to a pump source with the terminator 26 via the housing 152 in which the pump source 18 is accommodated in a recess 153, preferably gas-tight. A seal 146 assures that the [terminal] terminator 26 likewise terminates gas-tight, so that no dirt particles can penetrate into the recess from the outside and, as needed, it can be evacuated or filled with a protective atmosphere. A constant current of a protective atmosphere can also flow through the recess 153, particularly given temporary removal of the terminator 26. The radiation of the pump source 18 is focused onto the pump cross-section of the laser fiber 5 via a lens 154. The pump source can be composed of one or more laser diodes; however, it can also be composed of an arrangement of one or more lasers, particularly fiber lasers as well, whose output radiation was united such with suitable means that a suitable pump spot arises.

Fig. 15 shows the branching of the output radiation from the laser fiber 5 of a fiber laser with a fused fiber coupler 155. Such fused fiber couplers are described for single-mode fibers on Page G16 of the catalog of Spindler and

Hoyer specified in greater detail under Fig. 20 and can be directly fused to the output of the laser fiber 5 after correspondingly precise alignment. In this case, thus, the terminator 26, 94 is connected to a passive single-mode fiber or, respectively, to a different fiber 28 and not directly to a fiber laser with the active laser fiber 5. There are also other possibilities of splitting the laser beam into a plurality of sub-beams such as, for example, beam splitter mirrors or holographic beam splitters. The advantage of the described fused fiber coupler, however, is that the laser radiation can be brought to the processing point guided within fibers insofar as possible, this leading to a considerable simplification of the arrangement.

Fig. 16 shows the uniting of the radiation from the laser fibers 5 of two fiber lasers via a fused fiber coupler 156. The cross-sections of the two input fibers are united to form one fiber in the fused fiber coupler 156. For example, the diameter of the fibers at the two inputs of the fused fiber coupler amounts to 6 µm and the core diameter of the two laser fibers to be fused on likewise amounts to 6 µm. A core diameter of the single-mode fiber at the output of the fused fiber coupler thus becomes 9 µm, which still allows a faultless guidance of a single mode for the corresponding wavelength. The diameter at the output of the fused fiber coupler, however, can also be greater than 9 µm, and more than two outputs of fiber lasers or, respectively, fibers can be united. The terminator 26, 94 in this case is thus connected to a passive single-mode fiber or other passive fiber 28 and not to a fiber laser with the active laser fiber 5.

However, all other types of light waveguides can be welded to the fiber laser or coupled thereto in some other way, for example via optics.

One or more passive single-mode fibers or one or more other passive fibers 28 can also be coupled to an individual fiber laser instead of a brancher according to Fig. 15 or a combiner according to Fig. 16, being coupled via optics in order to then connect the terminator to this single-mode fiber or other fiber.

However, it is also possible to unite the outputs of a plurality of fiber lasers or single-mode fibers or other suitable fibers into which laser radiation can

be coupled via wavelength-dependent or polarized beam combiners or other suitable techniques, and to in turn couple into single-mode fibers or other fibers that can be provided with a respective, corresponding terminator at one or both ends.

The described possibilities of branching and uniting fibers can be particularly advantageously employed when the inventive modular structure is applied to the laser radiation source.

Fig. 17 shows the principle of an acousto-optical deflector. A piezo-electric transducer 45 is applied on a substrate 161 that is also referred to as crystal, said piezo-electric transducer 45 being supplied with electrical energy from a high-frequency source 162. The laser beam 163 incident at a Bragg angle α_B is deflected out of its direction proportionably to the frequency of the high-frequency source by interaction with the ultrasound field 164 within the crystal. When the beam that is not deflected and that passes through the modulator [at the moment] in a straight line is referenced I_0 (beam of the zero order), then the frequency f_1 yields a direction I_{11} (first beam of the first order), and the frequency f_2 yields a direction I_{12} (second beam of the first order). Both frequencies can also be simultaneously present and the beams I_{11} and I_{12} arise simultaneously, these being capable of being modulated by varying the amplitudes of the high-frequency sources. An optimum transmission efficiency for the infed radiation respectively derives when the Bragg angle amounts to half the angle between the direction of the [ray] beam bundle I_0 and the direction of the deflected [ray] beam bundle. For use as acousto-optical modulator, only one of the sub-beams is used. It is mostly effective for processing materials to employ the beam of the zero order because it has the higher power. However, it is also possible to use one or more beams of the first order. The energy of the beams that is not used is neutralized in that, for example, it is converted into heat on a cooling surface. Only one piezo-electric transducer 45 is provided in Fig. 17, for which reason only one laser beam 163 can be deflected or modulated. However, a plurality of piezo-electric transducers can also be attached on the same substrate

in order to thus simultaneously provide a plurality of laser beams, i.e. a plurality of channels, with different deflection or modulation signals. The individual channels are referenced T_1 through T_n. When, as shown in Fig. 17, the acousto-optical modulator is placed into a focal point of the lens 165 and the beam path is implemented nearly parallel through the acousto-optical modulator, the beams in the other focal point of the lens 165 are focused on the processing surface arranged here, and the beam axes between the lens 165 and the processing surface 81 proceed parallel and impinge the processing surface perpendicularly. Such an arrangement is called [telocentric] telecentric; the advantage is that the spacing between the beam axes remains constant when the position of the processing surface changes. This is of great significance for a precise processing of material.

Fig. 18 shows how the unused beam is neutralized. The unused beam is intercepted and deflected via a highly reflective mirror 166, which is preferably manufactured of metal for better heat elimination, is dispersed by a concave lens 75 and is directed onto an obliquely arranged plate 86 having bores 87 such that no energy can be reflected back into the laser. The plate 86 and, potentially, the mirror 166 are also cooled via a cooling system that is operated by a pump 167. It is also possible to utilize a convex lens [of] on a glass plate instead of the concave lens. The convex lens, particularly when a dispersion of the [ray] beam bundle to be neutralized can be undertaken with other techniques, which can occur, for example, by special shaping of the highly reflective mirror 166, is described under Fig. 4c. The concave lens 75 can also be omitted when one foregoes the advantage of the complete sealing of the laser gun. The plate 86 is shown with a planar surface at an angle. A plate having an arc or a cavity can also be employed. The surface can be roughened in order to absorb the laser energy well which is conducted to the coolant.

It is advantageous for an arrangement having a plurality of tracks to arrange a plurality of such modulators on a common crystal 34 according to Figs. 19 and 19a. The individual modulators cannot be arranged arbitrarily close to one

another because of too much heating. A modulator of Crystal Technology Incorporated, Palo Alto, USA, is especially suited for the inventive arrangement, this being distributed under the designation MC 80 and containing five separate deflection or modulator channels. In this case, the spacing of the channels is predetermined at 2.5 mm, whereby the beam diameter is recited as 0.6 mm through 0.8 mm. A similar product by the same company is equipped with ten channels having a spacing of 2.5 mm. The spacing of the channels of 2.5 mm requires the diameter or the edge length of the terminators 26, 94 is implemented smaller than 2.5 mm. When the terminator 26, 94, however, is greater in diameter or in edge length than the spacing of the channels in acousto-optical deflector or modulator, an adaptation can be undertaken with an intermediate imaging, as shown in Fig. 25. Such a multi-channel deflector or modulator can also be employed in the exemplary embodiments according to Figs. 4, 4a, 4b, 4c, 36, 36a and 37. Dependent on the requirement of the application, all channels need not be used. Only four channels are shown in the illustrated applied examples.

Instead of the acousto-optical modulator, however, it is also possible to utilize other modulators, for example what are referred to as electro-optical modulators. Electro-optical modulators are described under the terms "laser modulators", "phase modulators" and "Pockels cells" on pages F16 through F33 of the overall catalog G3, Order No. 650020 of Laser Spindler & Hoyer, Göttingen. Multi-channel electro-optical modulators have also been possibly employed, which is shown in the publication "Der Laser in der Druckindustries" by Werner Hülsbuch, Verlag W. Hülsbusch, Constance, page 523, Fig. 8-90a. When a one-channel or multi-channel electro-optical modulator is employed in combination with a birefringent material, then each laser beam can be split into two beams that can be separately modulated via further modulators. Such an arrangement is also referred to as an electro-optical deflector in the literature.

Fig. 18a shows an arrangement having an electro-optical modulator 168. In an electro-optical modulator, for example, the polarization direction of the laser radiation that is not wanted for processing is separated from the incident [ray]

beam bundle 163, and turned (P_b), and subsequently, the laser radiation P_b not wanted for the processing is separated off in a polarization-dependent beam splitter, which is also referred to as polarization-dependent mirror 169, and is conducted into a sump, for example into a heat exchanger that can be composed of a cooled plate 86. The radiation P_a wanted for processing is not turned in terms of polarization direction and is supplied to the processing surface via the lens 165. In the exemplary embodiments according to Figs. 4, 4b and 4c, the single-channel or multi-channel acousto-optical modulators 34 can be replaced by corresponding, single-channel or multi-channel electro-optical modulators. In the exemplary embodiments according to Figs. 4, 4b and 4c, the highly reflective mirror 74, 97 can likewise be replaced by the polarization-dependent mirror 169 (Fig. 18a), wherefrom an intercept arrangement 78 derives, and whereby the polarization-dependent mirror extends into the beam path desired for the processing.

The fiber laser can also be directly modulated. Such directly modulatable fiber lasers that have a separate modulation input available to them are offered, for example, by IPG Laser GmbH D-57299 Burbach, under the designation "Modell [YPLM] YLPM Series". The advantage is that the acousto-optical modulators and the corresponding electronics for the high-frequency sources can be omitted. Moreover, the transmission unit can be simplified, as shown in Fig. 23.

Fig. 19 shows a plan view onto an acousto-optical deflector or modulator. It is mentioned in the description of Figs. 4, 4b and 4c that the space 44 or 111 according to Figs. 4, 4b and 4c wherein the modulators are arranged should be optimally free of those components that give off particles or gases because particles could thus settle onto the highly stressed optical surfaces, which would lead to the premature failure of the arrangement. For this reason, the electrical components of the arrangement in Figs. 19 and 19a are arranged on a separate printed circuit board 171 that merely has two arms projecting into the sealed space and produces the electrical connections to the piezo-electrical [sensors]

transducers 45. The printed circuit board 171 is sealed relative to the modulator housing 172, preferably with a solder location 173. The end face of the printed circuit board is preferably sealed by a metal band (not shown) that is soldered on in the region of the space 44 or 111. The printed circuit board is implemented in multi-layer fashion in order to shield the individual high-frequency channels by interposed connections to ground. Instead of a printed circuit board, some other line arrangement can also be utilized. For example, each radio frequency channel can be connected by its own shielded line. The modulator housing 172 contains an access opening 174 to the electrical components. The modulator crystal 34 can be metallized at its base area and is preferably secured on the modulator housing with a solder point or a glued connection 175. A connection 176 to a cooling system can be located directly under the fastening location in order to carry the waste heat off via the openings 87 with a coolant. The modulator housing 172 is preferably closed by a cover 177 that carries the electrical terminals 181 and also contains the connections for the cooling system, but this is not shown. A seal 43 sees to it that the modulator housing 172 is inserted gas-tight into the housing 35 or 93 of Figs. 4, 4a, 4b and 4c and is secured with the connection 42.

It is possible to secure the electro-optical modulator 168 to the modulator housing (172) in a similar way and to contact it via the printed circuit board 171.

Fig. 20 indicates that the basic beam path for the exemplary embodiment of Fig. 4 for the [ray beams] beam bundles 144 of the corresponding fiber lasers F_{HD1} through F_{HD4}. The [ray] beams bundles of the fiber lasers F_{VD1} through F_{VD4} proceed partially congruently with the indicated rays but, inventively, have a different wavelength and, as can be seen from Fig. 4a, are united via a wavelength-dependent mirror 37 (not shown in Fig. 20) with the beam packet F_{HD1} through F_{HD4} to form the beam packet F_{D1} through F_{D4}. Further, Fig. 20 does not show the beam packets of the fiber lasers F_{VR1} through F_{VR4} and F_{HR1} through F_{HR4} that, as can be seen from Fig. 4a, are likewise combined via a wavelength-dependent mirror to form the beam packet F_{R1} through F_{R4}. As can be seen from the arrangement of the strip mirror 46 in Fig. 4a, the [ray beams] beam

bundles of the beam packet F_{R1} through F_{R4} in Fig. 20 would proceed offset by half a track spacing from the indicated rays. Instead of containing the indicated four [ray beams] beam bundles, thus the complete beam path contains a total of eight [ray beams] beam bundles that yield a total of eight separate tracks on the processing surface. Fig. 20 only shows the two [ray beams] beam bundles 144 of the fiber lasers F F_{HD1} and $F_{HD4.}$ As already mentioned under Fig. 4, however, a plurality of tracks can also be arranged; for example, the plurality of tracks on the processing surface can also be increased to sixteen separately modulatable tracks. On the basis of a digital modulation of the respective laser, i.e. the laser is operated in only two conditions as a result of turn-on and turn-off, this arrangement enables an especially simple control and a good shaping of the processing spot on the processing surface. This digital type of modulation requires only [one] an especially simple modulation system.

A distinction between more than 100 tonal value levels is required in high-grade multi-color printing in order to obtain adequately smooth color progressions; more than 400 tonal value stages would be optimum. When, for example, a cup in rotogravure wherein the volume of the cups determines the amount of ink applied onto the material being printed is composed of 8 x 8 or 16 x 16 small individual cups and the cup depth is kept constant, the processed surface can be quantitized into 64 or 256 stages. When, however, the cup depth is controlled by additional, analog or digital amplitude modulation or by a pulse-duration modulation of the laser energy, the volume of the cups can be arbitrarily finely quantized even given a low plurality of tracks. If, for example, the cup depth were digitally controlled in only two stages, as described in greater detail under Fig. 28, a cup could be composed of 8 x 8 individual cups given eight tracks, these potentially having respectively two different depths. For example, the volume of the cups in this case could be quantized in 128 stages without losing the advantage of purely digital modulation, which yields a considerable advantage for the stability of the method. Given 16 tracks and 2 stages in the cup depth, the number of digitally possible quantization stages already amounts to 512. It is also

possible to generate the cups in two processing passes in order to increase the number of tonal value steps.

The modulators 34 as well as the strip mirror 46 are not shown in Fig. 20. For a better illustration, the cross-section of the [ray] beam <u>bundle</u> 144 from the terminator of the fiber laser F_{HD1} that is congruent with the ray beam F_{D1} after passing the wavelength-dependent mirror is designed with a hatching. Like all other illustrations, this illustration is not to scale. The two illustrated [ray beams] <u>beam bundles</u> 144 yield the processing points B_1 and B_4 on the processing surface 81 that contribute to the built-up of the processing spot 24 and generate corresponding processing tracks on the processing surface 81. The axes of the terminators 26 and of the [ray beams] <u>beam bundles</u> 144 of the individual fiber lasers proceed parallel to one another in Fig. 20. The beam cones of the terminators, i.e. the shape of the ray beam 144, are shown slightly divergent. In the Figure, a beam narrowing within the lens 133 is assumed in the Figure. The divergence angle is inversely proportional to the diameter of the [ray] <u>beam</u> bundle in the corresponding beam narrowing. The position of the beam narrowing and its diameter, however, can be influenced by varying the lens 133 in the terminator 26, 94 and/or its distance from the fiber 28 or from the laser fiber 5. The calculation of the beam path occurs in the known way. See the technical explanations on pages K16 and K17 of the general catalog G3, Order No. 650020 of Laser Spindler & Hoyer, Göttingen. The objective is that the processing points B_1 through B_n of the processing surface 81 respectively become beam narrowings in order to obtain the highest power density in the processing points. With the assistance of the two lenses 55 and 56, beam narrowings and track spacings from the object plane 182 wherein the lenses 133 of the terminators 26 lie are imaged in demagnified fashion in an intermediate image plane 183 corresponding to the ratio of the focal lengths of the lenses 55 and 56. When, in this case, the distance of the lens 55 from the terminator 26 and from the crossing point 184 is equal to its focal length and when the distance of the lens 56 from the intermediate image plane 183 is equal to its focal length and equal to its spacing from the crossing

point 184, what is referred to as a telecentric imaging is obtained, i.e. the axes of the [ray] <u>beam</u> bundles belonging to the individual tracks begin to proceed parallel in the intermediate image plane. The divergence, however, has been noticeably increased. The preferably telecentric imaging has the advantage that the diameters of the following lenses 57 and 61 need only be insignificantly larger than the diameter of a [ray] <u>beam</u> bundle. The lenses 57 and 61 demagnify the image from the intermediate image plane 183 in a second stage onto the processing surface 81 in the described way. A preferably telecentric imaging, namely that the axes of the individual [ray beams] <u>beam bundles</u> proceed parallel between the objective lens 61 and the processing surface 81, has the advantage here that changes in spacing between the processing surface and the laser gun produce no change in the track spacing, which is very important for a precise processing. The imaging need not necessarily occur in two stages with two lenses each; there are other arrangements that can also generate parallel beam axes between objective lens and processing surface, as shown in Figures 21 and 22. Deviations in the parallelism of the beam axes between the objective lens 61 and the processing surface 81 can also be tolerated as long as the result of the processing of the material is satisfactory.

Fig. 21 shows a fundamental beam path for the exemplary embodiment of Fig. 4b. The illustration is not to scale. As was already the case in Fig. 20, the two [ray] <u>beam</u> bundles 144 of the lasers F_{HD1} and F_{HD4} are only a matter of a sub-set of the [ray] <u>beam</u> bundles of all existing lasers in order to explain the principle. In contrast to Fig. 20, however, the axes of the individual [ray] <u>beam</u> bundles of the terminators in Fig. 21 are not parallel but are arranged at an angle relative to one another, which is shown in greater detail in Fig. 24, and which is advantageously achieved by terminators 94 according to Figs. 10, 10a and 10b. As a result of this arrangement, the individual [ray] <u>beam</u> bundles 144 would cross similar to the case in Fig. 20 without a lens 55 being required. In the region of the imaginary crossing point, the dispersive lens with a short focal length, i.e. a concave lens 101 is inserted, this bending of the incoming rays off and rendering

of the [ray] beam bundles divergent is shown, i.e. widening them. The convex lens 102 is preferably arranged in the intersection of the axial rays and, together with the lens 101, forms an inverted Galileo telescope. As a result thereof, for example, parallel input [ray] beam bundles are converted into parallel output [ray] beam bundles having an enlarged diameter between the lenses 102 and 103. The desired parallelism of each input [ray] beam bundle can, as already described, be undertaken by a suitable selection of focal length and spacing of the lens 133 from the fiber 28 or laser fiber 5 in the terminators 26, 94. The objective lens 103 focuses the enlarged [ray] beam bundle onto the processing surface 81 at the processing points B_1 through B_4 that contribute to the [built] build-up of the processing spot 24 and generate corresponding processing tracks on the processing surface 81. The imaging scale can be modified in a simple way by modifying the focal length of the lens 103. It is therefore advantageous when the lens 103 is implemented as an interchangeable objective lens. As already described, however, a vario-focusing optics can also be employed. When the position of the lens 103 is selected such that the distance between the lenses 102 and 103 corresponds to the focal length of the lens 103, the axes of the [ray] beam bundles between the lens 103 and the processing surface are parallel and yield constant spacings of the tracks of the processing surface, even given a modified distance between the laser gun and the processing surface.

Fig. 22 indicates the fundamental beam path for the exemplary embodiment of Fig. 4c. Like all other figures, the illustration is not to scale. The beam path is very similar to that of Fig. 21, with the difference that an arced mirror 121 is employed instead of the lens 101 and a concave mirror 115 is employed instead of the lens 102. The beam path is considerably shorter due to the folding that derives. The beam path approximately corresponds to that of an inverted mirror telescope. Mirror telescopes are independent of the wavelength which is advantageous given employment of lasers having different wavelength. The imaging errors can be reduced by employing aspherical surfaces or with an optical correction plate 117 that, however, is not shown in Fig. 22. It is

advantageous [from] when the focal length of the objective lens 112 is equal to its spacing from the concave mirror. The axes of the ray bundles are then parallel between the lens 112 and the processing surface 81 and yield constant spacings of the tracks on the processing surface, even given a modified distance between the laser gun and the processing surface. Moreover, an advantageously large spacing of the objective lens from the processing surface derives. As described a vario-focusing optics can also be utilized.

Fig. 23 shows an arrangement having a plurality of lasers, whereby the individual laser outputs in the form of the terminators 26 are arranged on a circular segment and [beam] aim at a common cross-over point 185. This arrangement is particularly suitable for directly modulatable lasers since a very low expense then results. In such an arrangement, the imaging on the processing surface 81 can occur with only a single lens 186. However, an arrangement according to Figs. 4b or 4c can also be employed for imaging. The ray cones of the [ray] beam bundles from the terminators are set such that a beam narrowing and, thus, a sharp image derives for all lasers on the processing surface 81. Preferably, the spacings between the cross-over point 185 and the lens 186 as well as between the lens 186 and the processing surface 81 are of the same size and correspond to the focal length of the lens 186. In this case, the axes of the individual ray bundles between the lens 186 and the processing surface 81 are parallel and yield constant spacings between the processing tracks, even given a modified distance between the laser gun and the processing surface. Although not shown, a plurality of levels of lasers can also be arranged above one another in order to increase the power density and the power of the laser radiation source. The planes of the lasers are preferably arranged parallel to one another. As shown in Figs. 29 and 31, it then derives that the individual ray bundles from the individual planes meet on a spot in the processing points on the processing surface 81 and thus generate an especially high power density.

Fig. 24 shows a modification relating to Fig. 23. Four fiber lasers F_{HD1}, F_{HD2}, F_{HD3}, F_{HD4} have their terminators 94, which are described in greater detail in

Figs. 10, 10a and 10b, joined to one another on a circular segment. The terminators 94 are particularly suited for joining to one another as a result of their shape. Since no directly modulatable fiber lasers are employed here, a four-channel acousto-optical modulator 34 is inserted. The piezo-electric [sensors] transducers 45 can, as shown in Fig. 24, likewise be arranged on a circular segment. As shown in Fig. 24a, however, they can also be arranged parallel as long as the ray bundles are still adequately acquired by the acoustic field of the piezo-electric [sensors] transducers 45. Instead of the lens 186, a transmission unit as described in Figs. 4b and 4c is advantageously employed.

Fig. 25 indicates a demagnifiying intermediate [image] imager with the [lense] lenses 191 and 192, so that the distance between the individual terminators 26, 94 can be greater than the distance between the individual modulator channels T1 through T4 on the multi-channel acousto-optical modulator 34. The imaging ratio corresponds to the relationship of the focal lengths of the two lenses 191 and 192. The intermediate image is preferably telecentrically designed in that the distance of the lens 191 from the lenses 133 of the terminators 26 or 94 and from the cross-over point 193 is equal to its focal length, and in that the distance from the crossing point 193 to the lens 192 as well as the distance of the lens 192 from the modulator crystal 34 is equal to its focal length. By adjusting the distance between the two lenses, however, one can also achieve that the rays emerging from the lens 192 no longer proceed parallel but at an angle relative to one another in order to connect the beam path according to Figs. 21 or 22 thereto. An intermediate image according to Fig. 25 can also be employed in combination with an arrangement of the terminators on a circular segment according to Figs. 23 and 24.

The intermediate [image] imager (191, 192) is shown in Fig. 25 between the terminators (26, 94) and the modulator (34). However, a wavelength-dependent or polarization-dependent mirror 37 can also be arranged preceding or following the intermediate [image] imager in the beam direction. An intermediate [image] imager (191, 192) can also be arranged in the beam path

following the modulator, before or after the strip mirror 46. Preferably, the intermediate [image] imager in the beam path is inserted at the locations referenced "E" in Fig. 4a.

Figs. 26 and 26a show how the distance between the tracks in the processing plane can be reduced. Fig. 26 is a side view and Fig. 26a is the appertaining plan view. Since the [ray] beam bundles 144 emerging from the terminators 26, 94 have a smaller diameter than the housing of the terminators, interspaces remain that are not utilized. Moreover, the minimum distances between the tracks and the maximum diameters of the [ray] beam bundles are prescribed by the multi-channel acoustic-optical modulators 34. In order to [increase] decrease the distances between the tracks, a strip mirror 46 is provided that is transparent and mirrored in alternating fashion in stripe-shaped fashion at intervals. The strip mirror 46 and the modulators are not shown in Fig. 26a. Such a strip mirror 46 is shown in Figures 27 and 27a, whereby Fig. 27a shows a side view of Fig. 27. Highly reflective strips 195 are applied on a suitable substrate 194 that is transparent for laser radiation. The interspaces 196 as well as the backside are preferably provided with a reflection-reducing layer. The [ray] beam bundles 144 from the terminators 26, 94 of the fiber lasers F_{D1} through F_{D4} pass unimpeded through the transparent part of the strip mirror 46. The [ray] beam bundles 144 from the terminators 26, 94 of the fiber lasers F_{R1} through F_{R4} are arranged such that they are reflected at the strips of the strip mirror such that that they lie in a row with the ray bundles F_{D1} through F_{D4}. The distance between the tracks has thus been cut in half.

Fig. 27b shows a strip mirror 46, whereby the substrate of the mirror was removed in the interspaces 196, and the entire, remaining surface is preferably highly reflectively mirrored, so that strips 195 derive. In this case, the strip mirrors can be preferably manufactured of metal, which is especially advantageous given high powers and the heating connected therewith.

An arrangement having strip mirrors can be combined very well with an arrangement having wavelength-dependent mirrors, as shown, for example, in

Figures 4, 4a, 4b, 4c. The further beam path according to Fig. 20 can be connected [vi] <u>via</u> the lens 55. The axes of the individual terminators 26, 94, however, can also be arranged at an angle, as shown in Figs. 23 and 24. In this case, the further beam path can proceed according to Fig. 21 or 22 and the lens 55 is omitted.

Figs. 28 and 28a show how fiber lasers of different wavelength, for example Nd:YAG lasers having 1060 nm and those having a different doping with 1100 nm are combined with one another via a wavelength-dependent mirror 37. The wavelength difference can be less but can also be greater.

The modulators and the wavelength-dependent mirror are not shown in Fig. 28a. Preferably, wavelength-dependent mirrors are optical interference filters that are manufactured by vapor-deposition of suitable dielectric layers onto a substrate that is transparent for the appertaining wavelengths and can have very steep filter edges as high-pass or low-pass filters. Wavelengths up to the filter edge are allowed to pass; wavelengths beyond the filter edge are reflected. Band-pass filters are also possible. Likewise, lasers of the same wavelength but a different polarization direction can be combined via polarized beam combiners, preferably polarization prisms. Inventively, a combination of polarized beam combiners and wavelength-dependent mirrors is also possible. In Fig. 28, the [ray] <u>beam</u> bundles 144 emerging from the terminators 26, 94 of the fiber lasers F_{HD1} through F_{HD4} with the wavelength λ_1, pass unimpeded through a wavelength-dependent mirror 37, whereas the [ray] <u>beam</u> bundles F_{VD1} through F_{VD4} having the wavelength λ_2 are reflected at it and, thus, the two [ray] <u>beam</u> bundles are united in one another following the mirror. Each [ray] <u>beam</u> bundle can be separately modulated according to the invention via a respective multi-channel, [acoustic] <u>acousto</u>-optical modulator 34. Since respectively two lasers of different wavelengths process the same track in the same processing point on the processing surface, a digital amplitude modulation in 2 stages is possible in a simple way in order, for example, to control the depth of the cups when producing printing forms for rotogravure when the two participating [ray]

beam bundles are respectively merely turned on or off. However, a shared modulator for the two united [ray] beam bundles can also be employed. In this case, the modulator is arranged between the wavelength-dependent mirror 37 and the lens 55, as shown in Figs. 4, 4a, 4b, 4c. The further beam path of the transmission unit according to Fig. 20 connects via the lens 55. However, the axes of individual terminators 26, 94 can also be arranged at an angle relative to one another, as shown in Figs. 23 and 24. In this case, the further beam path can proceed according to Fig. 21 or 22 and the lens 55 can be omitted.

Fig. 29 shows how fiber lasers with their terminators 26, 94 (Fig. 31) can be arranged in a plurality of planes. Three planes of terminators that are connected to fiber lasers lie above one another. The first track is referenced F_1 for the first plane, with F_2 for the second plane and with F_3 for the third plane. The numerals 11, 12 and 13 reference the first plane of the further tracks. The axes of the [ray] beam bundles 144 emerging from the terminators are directed parallel to one another in the individual planes. The axes of the [ray] beam bundles of the individual tracks can proceed parallel to one another, as shown in Fig. 20, or at an angle relative to one another according to Fig. 23 or 24.

In Fig. 30, the terminators 26, 94 (Fig. 31) of, for example, seven fiber lasers F_1 through F_7 are arranged in a hexagon such that the axes of their ray bundles 144 are parallel to one another. To this end, terminators according to Fig. 12 can be advantageously employed. As a result thereof, the smallest possible diameter of a common ray bundle composed of seven individual ray bundles derives.

First, Fig. 31 is first a sectional view through the three planes of the first track of Fig. 29. A lens 107 collects all incoming parallel rays in its focal point 201 on the processing surface 81. As a result thereof, power and power density are multiplied by the plurality of lasers united in the focal point, i.e. are tripled given three planes. When the axes of the [ray] beam bundles emerging from the terminators 26, 94 proceed parallel to one another for tracks and planes, the [ray] beam bundles of all tracks would likewise be additionally united in the focal

point, and a common processing point would arise on the processing surface that generates a processing track. When the axes of the beam bundles emerging from the terminations 26 proceed under an angle as shown in Fig. 23 or 24, every track of termination will generate a processing point, which generates a processing track I.e., the same number of processing tracks are registered next to one another as there are tracks of terminators. The power of the [ray] beam beams of the various planes is superimposed in the respective processing point and the power density is tripled in the illustrated example. The individual fiber lasers can thereby be directly modulated; however, external modulators can also be employed. Figs. 32 and 33 describe how a multiple-channel acousto-optical modulator corresponding to the number of tracks can be preferably employed for the simultaneous modulation of all ray bundles of the various planes.

Fig. 31 is also a sectional view through the bundle arrangement according to Fig. 30. It is known that parallel ray bundles that are incident into a lens have a common focus. Page 13, Fig. 2.21 in the book "Optik und Atomphysik" by R. W. Pohl, 13th edition, 1976, Springer Verlag shows such an arrangement. Further, DE-A-196 03 111 discloses an arrangement wherein, as can be seen from Fig. 1 therein, the radiation from a plurality of laser diodes is respectively coupled into a single-mode fiber, the radiation at the output of each fiber is collimated to a respective, parallel [ray] beam bundle, and all parallel [ray] beam bundles are directed onto a common spot with a shared lens in order to achieve an increased power density. Compared to the arrangement shown in Fig. 31 with fiber lasers, however, this arrangement has serious disadvantages. When radiation is to be efficiently coupled into single-mode fibers, single-mode laser diodes are required for this purpose so that the aperture of the single-mode fibers is not overfilled and the total radiation can be transmitted into the core of the single-mode fiber. Single-mode laser diodes, however, can only be manufactured with extremely limited power because the loadability of the minute laser mirrors represents a technological barrier. Single-mode laser diodes are therefore only available up to an output power of approximately 200 mW and are far more expensive per watt

[then] than multi-mode diodes that are offered with radiation powers of up to several kilowatts. Given single-mode fibers for 800 nm wavelength, the product of core diameter and numerical aperture amounts to approximately 5 µm x 0.11 = 0.55 µm, whereas this lies at 300 µm x 0.4 = 120 µm given a fiber laser having a typical diameter of the pump fiber of 300 µm and a numerical aperture of 0.4, which amounts to a factor of 220. When the area ratio of the two fibers is considered, then a factor of $(300/5)^2 = 3600$ derives. Even when a reduction of the laser radiation by the factor of the absorption efficiency of approximately 0.6 is assumed given the fiber laser, this being the efficiency with which the pump radiation is converted into laser radiation, the power of the laser radiation that can be achieved at the output of a fiber laser is several orders of magnitude higher [then] than the power at the output of a single-mode fiber. Even if single-mode diodes or other laser radiation sources having very high power were available, it would nonetheless not be possible to couple this satisfactorily into single-mode fibers, since the fibers would burn given the slightest misadjustment at the fiber entry. This problem does not exist given fiber lasers since a relatively large fiber diameter is available for the pumping and the energy is transmitted into the single-mode core of the laser fibers only within the laser fiber, which is possible unproblemmatically and with good efficiency.

The lens 197 in Fig. 31 unites the entire power of all seven [ray] beam bundles F_1 through F_7 of the corresponding fiber lasers in its focal point 201 which represents the processing spot 24 on the processing surface 81. The power and the power density in the focal point thus become higher by the factor of 7 than is the case given an individual [ray] beam bundle. When, for example, 100 W are required in order to generate a required power density on the processing surface, then seven lasers having a radiant power of approximately 15 watts each suffice in this case. However, more than seven lasers can be provided. The lasers can preferably be directly modulated. However, it is also possible to modulate all seven [ray] beam bundles separately or overall with an external modulator or to supply a plurality of such bundle arrangements to a multi-channel modulator in

such a way that the modulator channels are preferably arranged in the focal point of a uniting lens 197 that is allocated to each bundle. It is also possible to couple the multiplied power of each and every bundle into fibers before or after the modulation. Further, such bundle arrangements can be advantageously utilized in laser guns according to Figs. 4, 4a, 4b, 4c.

It is advantageous to separately modulate the individual lasers. This is especially suitable when a high number of lasers is employed, since, for example, a quantized modulation that is similar to an analog modulation, a quasi-analog modulation of the united laser radiation is then enabled by digital modulation of the individual lasers. However, it is also possible to modulate the [ray] beam bundles 144 of all lasers in common, for example with an acousto-optical modulator. In this case, the ultrasound field of the modulator cell must exhibit such a size that the overall [ray] beam bundle shown in Fig. 30 can be modulated. However, the switching time of the acousto-optical modulator becomes so great as a result thereof that the shape of the cups to be engraved is disturbed as a consequence of the rotational movement of the drum containing the processing surface. However, it is possible to entrain the laser beam with a deflection motion in the direction of the rotary motion of the printing cylinder to be engraved during the engraving and to thereby achieve a processing spot 24 that is stationary on the processing surface. Inventively, the deflection motion can occur with the same acousto-optical modulator with which the amplitude modulation occurs. However, another acousto-optical cell can also be utilized, the deflection occurring therewith.

Fig. 32, in a farther-reaching example, shows how the power density on the processing surface can be considerably increased by providing terminators 26, 94 with the corresponding fiber lasers in a plurality of planes, but a modulation of all [ray] beam bundles 144 belonging to a track can be simultaneously implemented with a single-multi-channel, acousto-optical modulator 34 corresponding to the plurality of tracks. In this example, the terminators are arranged in three planes of n tracks each that lie above one another. The power of

all ray bundles 144 of all planes should be largely focused in a processing point in the processing surface for each track in order to achieve a high power density. The terminators 26, 94 are arranged parallel to one another in tracks and planes, since the terminators 26 are joined to one another in close proximity. As shown, terminators having a round cross-section can be employed for this purpose; preferably, however, terminators having a quadratic cross-section according to Figs. 9 and 9a are utilized. Given the parallel arrangement of the tracks, the illustrated imaging system having the cylindrical lenses 202 and 203, also refer to as cylinder optics, can, for example, be added analogous to an arrangement like that of Fig. 4. When the individual tracks are to proceed at an angle according to Figs. 23 or 24, terminators 94 according to Figs. 10, 10a and 10b are preferably employed. In this arrangement, too, the [ray] beam bundles of the individual planes remain parallel; the fits of the terminators 94 should proceed parallel in the side view of Fig. 10a for this purpose. When the axes of the ray bundles for the tracks proceed at an angle relative to one another, the cylinder optics having the lenses 202 and 203 can be added, for example analogous to the arrangements according to Figs. 4b or 4c. The [ray] beam bundles 144 emerging from the terminators are directed onto the convex cylinder lens 202 that would [ignite] combine the rays in its focus to form a line having the length of the beam diameter. A concave cylinder lens 203 having a shorter focal length then the cylinder lens 202 is attached such in the region of the focus of the cylinder lens 202, 203 having a long focal length such that its focus coincides with the focus of the cylinder lens 202. As a result thereof, the rays that leave the lens 203 become parallel again. The spacings between the individual planes, however, have been reduced by the ratio of the focal lengths of the two cylinder lenses compared to the spacings that the [ray] beam bundles had when they left the terminators 26, 94. The spacings of the [ray] beam bundles have remained unmodified in the direction of the tracks since the cylinder lenses exhibit no refractive effect in this direction. As a result thereof, elliptical beam cross-sections derive in the modulator. The purpose of this arrangement is to make the overall height of the

three ellipses lying above one another so small that it approximately corresponds to the major axis of the ellipses in order to create conditions in the channels of the acousto-optical modulator similar to those achieved given a round beam cross-section so that, for example, similarly short switching times can be achieved.

Fig. 33 shows that, however, the spacing of the two cylinder lenses can also be modified somewhat so that all three elliptical [ray] beam bundles overlap in the modulator, this is in fact yielding a shorter switching time in the acousto-optical modulator but also yielding an increased power density in the modulator crystal. The cylinder lens 203 can also be omitted for this purpose.

The cylinder optics (202, 203) is shown in Fig. 25 between the terminators (26, 94) and the modulator 3. However, a wavelength-dependent or polarization-dependent mirror 37 can also be arranged preceding or following the cylinder optics in beam direction. A cylinder optics (202, 203) can also be introduced in the beam path following the modulator, preceding or following the strip mirror 46. Preferably, the intermediate image is inserted in the beam path at the locations references "E" in Fig. 4a.

For removing the material eroded from the processing surface, Fig. 34 shows a mouthpiece 82 whose main job is to use a directed flow to [see to it] take care that optimally no clouds of gases and/or eroded material form in the optical beam path between objective lens and processing [service] surface 81, these clouds absorbing a part of the laser energy and depositing on the processing surface and thus negatively influencing the work result.

As a result of its specific shaping, the mouthpiece 82 prevents the described disadvantages. Preferably, it is secured to the laser gun with connections 204 that are simple to release, so that it can be removed and cleaned in a simple way and also enables a simple cleaning as well as a simple replacement of the objective lens (not shown) 61, 103, 112. A cylindrical bore 206 for adaptation to the objective lens and a preferably conical bore 207 as passage for the [ray] beam bundle as well as another preferably cylindrical bore

that represents the processing space 211 are located in a preferably cylindrical base member 205. The distance of the base member 205 from the processing surface 81 should not be excessively great. The processing points (not shown) for producing the individual processing tracks on the material to be processed lie in the processing spot 24. A broad, all around extraction channel 212 is preferably located in the base member, this channel 212 being connected to the processing space 211 via a plurality of extraction channels 213 that should have a large cross-section. Preferably, 3 through 6 extraction channels 213 are present. A further, preferably all around admission channel 214 is located in the base member, this channel 214 being connected via nozzle bores 215 to the processing space 211 and to the conical bore 207 via smaller bypass bores 216. 3 to 6 nozzle bores 215 and 3 to 20 bypass bores 216 are preferably distributed over the circumference of the admission channel 214. All bores can be offset relative to one another and relative to the extraction channels 213 on the circumference. Further bypass bores can also be attached and directed onto the objective lens. This, however, is not shown. The base member is surrounded by a ring 217 applied gas-tight that contains a plurality of extraction connectors 221 in the region of the channel 212 to which extraction hoses are connected, these being conducted via an extraction filter to a vacuum pump. The extraction hoses, the extraction filter and the vacuum pump are not shown in Fig. 34. In the region of the channel 214, the ring contains at least one admission connector 222 via which compressed air filtered with an admission hose is supplied. The quantity of admitted air can be set with a valve such that it is just adequate in order to adequately rinse the processing space and such that it generates a slight air stream along the conical bore via the bypass bores that largely prevents a penetration of particles into the conical bore. The admission hose, the valve and the filter are not shown in Fig.3 4. The nozzle bores 215 are directed such onto the processing spot 24 such that the clouds of gas, solid and molten material arising in the processing are quickly blown out of the beam path so that these absorb as little laser energy as possible and cannot negatively influence the processing result.

Oxidation-promoting or oxidation-inhibiting gases or other gases can also be blown in with the admission air, these having a positive influence on the processing process. A slight quantity of air from the environment co-flows through the processing space to the extraction channels through the gap between the processing surface and the base member 205; this, however, is not shown. The filter in the extraction line is attached easily accessible in the proximity of the mouthpiece and sees to keeping the vacuum pump clean. It is also possible to introduce the filter directly in the extraction channel 212. As described under Fig. 39a, it is useful when a protective atmosphere is additionally conducted over the objective lens. If the mouthpiece 82 becomes too hot due to the laser radiation reflected from the processing surface and the air that flows through does not suffice for cooling, then the mouthpiece can be provided with additional bores through which a coolant is pumped; this, however, is not shown in the Figs. A glass plate 218 that is highly anti-[bloomed] reflection coated on both sides and is simple to change can also be located within the cylindrical bore 205, this glass plate 218 keeping dirt particles away from the objective lens. The shape of the mouthpiece can also deviate from the form that is described and shown. For example, the bores need not be cylindrically or conically implemented, as described; they can be varied in shape. Likewise, for example, the nozzle bores and extraction channels can assume arbitrary shapes and can also be asymmetrically arranged. For example, the nozzle bores in Fig. 34 can be arranged more in the upper part of the Fig., whereas the extraction channels lie more in the lower part of the Figure. For example, the nozzle bores and/or the bypass bores can also be foregone. The shape of the mouthpiece can also be modified, particularly when the shape of the processing surface and the type of relative motion between processing surface and laser radiation source demand this. It is conceivable to utilize a modified form of the described mouthpiece when the material to be processed is located, for example, on a planar surface instead of on a drum surface, and the laser radiation is conducted past this line-by-line. In this case referred to as flatbed arrangement, which is shown in

greater detail in Figures 43, 43a and 43b, the mouthpiece is implemented elongated corresponding to the line length and is provided with an elongated processing space corresponding to its length. The mouthpiece is equipped with nozzle bores and extraction channels from one or from both sides. In this case, the glass plate would be given a rectangular shape and would extend over the entire length of the arrangement. In this case, Figure 34 could be analogously considered as a cross-section of the elongated mouthpiece. Even when the material to be processed is located in a hollow cylinder, which is not shown in detail in Figs 44a and 44b, a similar mouthpiece can be produced in that the mouthpiece described for the flatbed arrangement is adapted in the longitudinal direction to the shape of the hollow cylinder such that a slight gap between the processing surface and the mouthpiece derives over the entire length. The glass plate would be given a rectangular shape in this case and would be curved over the entire length of the arrangement.

[In a] A generally known scraper device that, however, is not shown in the figures can be located in the proximity of the mouthpiece but need not necessarily be connected to it or to the laser gun. For example, the job of the scraper device is to scrape off the ejects arising at the edges of the cups during the processing process at rotogravure forms. Further, a brush device (not shown) can preferably be located in the proximity of the laser gun, this brushing out the cups that have been cut and ridding them of adhering dirt. Further, a measuring device (not shown) can be preferably inventively located at the laser gun, this measuring the position and/or the volume of the cups immediately after they are produced. In contrast to cups that have been manufactured by electro-mechanical engraving or with a single laser beam, the volume can be inventively more precisely identified for cups that are produced with the inventive laser radiation source and have steep edges and constant depth, in that the area of the cup is determined with a specific, fast camera and the volume is derived therefrom. It is thereby advantageous to measure a series of cups in order to reduce measuring errors. It lies within the framework of the invention that specific control fields are engraved in a region of

the rotogravure cylinder, this being provided for monitoring measurements and/or for monitoring prints. A rated/actual comparison can be produced with this measured quantity for the generated cups and with the cup size prescribed for this location. The result can then be employed in order to correct the position and/or the volume of the subsequently produced cups.

Fig. 35 shows the conditions on the processing surface. The processing points are identified with the indices that indicate the ray bundles of the fiber lasers according to Figs. 4, 4a, 4b and 4c that produce them. For example, the ray bundles of the fiber lasers F_{VR1} and F_{HR1} generate the processing point $B_{FVR1+FHR1}$ in common to the diameter of the processing points is referenced B, and their spacing is referenced A. In the multi-channel, acousto-optical modulator described under Figs. 19 and 19a, the allowable diameter of the [ray] <u>beam</u> bundle 144 is smaller than the spacing of the channels of the modulator. The diameter of the ray bundle 144 in the terminators 26, 94 [can also] <u>cannot</u> be made just as large as the outside diameter of the terminators without great expense. It follows therefrom that A is thus greater than B. This leads to undesired interspaces at the processing tracks 224 that derive as a result of the relative motion between the material to be processed and the laser gun. The processing tracks have a track width D that corresponds [between] <u>with</u> the diameter of the processing points B and [R] <u>are</u> referenced <u>as</u> 1 through 8 in Fig. 35. In order to reduce these interspaces, two beam packets were already nested inside one another with the strip mirror, as described under Figs. 4, 4a, 26 and 26a, in order to cut the interspaces in half. In order to reduce the remaining interspaces even more, or to entirely avoid them or cause the processing tracks 224 to overlap, the laser gun can be turned such compared to the relative motion direction between the material to be processed and the laser gun such that the tracks come closer to one another, this being shown in Fig. 35. In order, for example, to achieve a spacing C of the processing tracks 224 that is equal to the diameter B of the processing points, the laser gun must be turned by the angle β according to the relationship $\cos \beta = B/A$. Distortions in the image information arise on the processing surface due to the

rotation of the laser gun, since the starts in the individual processing tracks are now shifted relative to one another. These distortions, however, are already compensated in the editing of the processing data. It is also possible to undertake this compensation by an adjustable, different delay of the signals in the individual data channels immediately before the modulation or to simply accept the distortions. Further possibilities for setting and reducing the spacings of the processing tracks are presented in Figs.36, 36a, 36b, 36c and 37.

Fig. 36 shows the principle of how processing points B_1...B_4 derive on the processing surface 81 when the individual channels are charged with different frequencies f_1 through f_4 in a multi-channel acousto-optical modulator 34 having four separate channels. For example, the modulator channel T_1 (Fig. 36a) is thereby supplied with a frequency f_1, whereby f_1 is provided with a higher frequency compared to f_4 in the modulator channel T_4 (Fig. 36a), so that a greater spacing of I_0 derives for the processing track 1 than for the processing track 4. The channels T_2 and T_3 are provided with corresponding frequencies f_2 and f_3 in order to achieve the illustrated arrangement of the processing tracks 224. However, the frequencies can also be arranged such that the frequency f_1 is lower then the frequency f_4. It is also possible to arbitrarily allocate the frequencies f_1 through f_4 to the individual modulator channels T_1 through T_4. In this case, a lens 165 as shown in Fig. 17 and Fig. 36a is not absolutely necessary; rather, the laser radiation emerging from the terminators can be focused such that a sharp image derives in the processing points on the processing surface.

How the [ray] beam bundles focused by the lens 165 impinge the generated line M of the drum is shown in Fig. 36a with reference to an example (not to scale) with the rotating drum on which the processing surface 81 lies. The position of the puncture points P of the ray axes with the plane of the lens 165 thereby corresponds to the principle of Fig. 36. For that purpose, the modulator 34 with the channels T_1 through T_4 is correspondingly arranged relative to the [ray] beam bundles 144 of the fiber lasers F_1 through F_4. What is achieved by a suitable selection of the frequencies f_1 through f_4 is that the partial rays that

generate the processing points B_1 through B_4 lie at desired distances from one another in the direction of the generated line M. This has the advantage that the position of each processing point and, thus, of each processing track 224 can be individually set by adjusting the corresponding frequency. A particular advantage of the arrangement derives when, as indicated in Fig. 17, the multi-channel acousto-optical modulator is arranged approximately in the one and the processing surface is arranged approximately in the other focal point of the lens 165, and the axes of the [ray] beam bundles of the fiber lasers F_1 through F_4 are arranged approximately in parallel planes. The processing points B_1 through B_4 then lie in a row on the generated line M [(](Fig. 36a), and the axes of the partial rays that form the processing points are parallel and reside perpendicularly on the processing surface (Fig. 17). Another advantage of the arrangement is that the Bragg angle for optimizing the efficiency can be individually set for each modulator channel, but this is not shown in the Figures. In this example, the deflected rays are used for processing material, whereas the non-deflected rays I_0 are blanked out by an intercept arrangement similar to that shown in Figure 18. In contrast to the arrangement in Figure 18, it is shown here that the mirror 166 acting as intercept arrangement can also be arranged between the lens 165 and the processing surface. As described under Fig. 4, however, the intercept arrangement can also be foregone when a symmetrical or asymmetrical defocussing reduces the radiation that is contained in I_0 and is unwanted for processing in terms of its power density to such an extent that no processing effect is produced when it is directed onto the processing surface.

Fig. 36b shows an expanded embodiment of Fig. 36a in a side view. The lenses 202 and 203 are inserted between the multi-channel modulator with the channels T_1 through T_n, said lenses 202 and 203 being preferably cylinder lenses and forming a cylinder optics, as described under Fig. 32 and Fig. 33. This cylinder optics demagnifies the distance between the channels T_1 and T_n at the location of the lens 166 and, given a predetermined focal length of the lens 165, thus, the angle at which the rays of the individual channels T_1 through T_n impinge

can also be employed. The emerging [ray] beam bundles can be imaged into the processing surface with the known arrangements; however, a receptacle can also be implemented, whereby the [ray] beam bundles are directly directed onto the processing surface, i.e. without transmission unit, in that, for example, the outputs of a laser radiation source according to Fig. 41 are brought extremely close to the processing surface or lie on the surface of the material in sliding fashion, this yielding an especially simple arrangement. Such a method can be employed, for example, when [convergence] changes in the surface of the material are to be excited by energy irradiation or when a material transfer is to be undertaken. In the example of a material transfer, a thin film is placed onto the material to be provided with images that, for example, can be a printing cylinder, an offset plate, an intermediate carrier or the material to be printed itself, a layer being applied to the underside of said thin film that faces to the material to be provided with images and that is stripped by energy irradiation and can be transferred onto the material to be provided with images.

Fig. 42 shows another embodiment of the laser radiation source that can be employed for multi-channel cutting and incising of, for example, semiconductor materials and as disclosed in German Patent Application P 198 40 936.2 of the assignee "Anordnung zum mehrkanaligen Schneiden und Ritzen von Materialien mittels Laserstrahlen" running parallel with and filed simultaneously with the present patent application. The terminators 26, 94 of the fibers or, respectively, fiber lasers F_a through F_n have ray bundles 144 that are focused with the lens 133 at a predetermined distance from the terminator. The diameter of the processing points B_a through B_n amounts, for example, to 20 µm; however, it can also lie thereabove or therebelow. Further, the terminators are arranged on a profiled rail 256 described in greater detail in Figs. 42 and 42b such that their mutual spacing "A" can be set to arbitrary values until the terminators meet one another. The profile rail is preferably secured to an arm of a robot (Fig. 42c) and can, for example, be moved in the directions x, y, z relative to ta table 225 with actuating drives that are shown in Figure 42c. Moreover, the profiled rail can be turned

the processing surface, is particularly significant given a great number of channels and significantly favors the costs for the lens 165, which can also be a system composed of a plurality of lenses, as well as its makeability.

Fig. 36c shows a plan view relating to Fig. 36b, from which it can be seen that the cylinder optics exhibits essentially no effect in this view. The ray bundles F_1 through F_n coupled into the acousto-optical modulator 161 are in fact shown under the same Bragg angle; however, they can also, however, be coupled in individually differently under the respectively optimum Bragg angle.

Fig. 37 emphasizes another advantage of the arrangements according to Figs. 36, 36a, 36b and 36c, namely that respectively two processing points B_{11}, B_{12} through B_{41}, B_{42} can now be generated instead of the processing points B_1 through B_4 by simultaneous application of two different frequencies to the respective modulator channels. Instead of four processing tracks, eight separately modulatable processing tracks 224 have now arisen without increasing the number of lasers and/or the number of modulator channels. It lies within the scope of the invention to also employ more than two frequencies per modulator. Twelve different frequencies with a single modulator channel have already been realized for a similar purpose. Another advantage in the generation of processing points with acousto-optical deflection is the possible shift of the processing points at high deflection speed. By modifying the applied frequencies, individual or all processing tracks 224 can be very quickly displaced relative to their previous position and there is thus a further possibility of beneficially influencing the position and shape of the cups. With this technique, in particular, the position of the processing tracks can be correspondingly readjusted to a rated quantity with high precision. Precisions of a fraction of a track width are thereby possible. Inventively, the actual position of the individual processing tracks can be precisely determined with a known, interferometrically functioning measuring system in that, for example, the actual position of the laser radiation source is registered during the processing event and a correction signal for the required displacement and readjustment of the processing tracks is generated by

comparison to the rated position of the processing tracks. This can be of interest particularly when a seamless joint is to be made to a processing pattern that already exists or when a pattern that already exists is to be post-processed. Another enormous advantage of the arrangement is that the Bragg angle can be individually set for optimizing the efficiency for each modulator channel, which, however, is not shown in the Figures. Up to now, acousto-optical arrangements wherein a plurality of sub-beams are generated from a laser beam by applying a plurality of frequencies wherein all of these have a shared Bragg angle for all sub-beams, has not yet made a breakthrough in processing of materials because the efficiency is too low. When, however, a combination of a number of laser beams having respectively individually set Bragg angle and a number of acousto-optically generated sub-beams per laser beam is selected as proposed, then a clearly higher efficiency can be achieved, so that a great plurality of simultaneously acting processing tracks can be realized for processing material.

As described under Figs. 18 and 18a, however, single-channel or multi-channel electro-optical modulators can also be utilized in conjunction with a birefringent material in order to split each laser beam into two beams that can be separately modulated via further electro-optical or acousto-optical modulators.

It has been emphasized that the processing of the material in Figs. 36, 36a, 36b, 36c and 37 should occur with the deflected laser beams and that the radiation contained the non-deflected ray laser beam is to be neutralized, so that no processing effect is produced. This, however, is not absolutely necessary, and instances are conceivable wherein one works conversely. A further advantage of the arrangement shall therefore be cited and explained with reference to Fig. 36a wherein one wishes to employ the radiation contained in the laser beams I_0 for processing material, the mirror 166 is removed. The entire radiant power from all four lasers F_1 through F_4 thus derives on the generated line in a spot. More than four times the power density thus derives in the spot compared to the previous processing points B_1 through B_4, and it can be assumed that no processing effect arises in B_1 through B_4 given specific materials and process parameters. Ie., the

processing surface simultaneously serves as a sump for the radiation that is not intended to produce any processing effect. This is advantageous since a thermal equilibrium occurs on the processing surface since the entire laser energy is supplied to the processing surface in every case. It lies within the scope of the invention that fewer or more than four lasers with corresponding modulator channels are utilized and that the difference in the power density between the radiation that is intended to produce a processing effect and the radiation that should not produce any processing effect is increased per modulation channel by employing more than one frequency per modulator channel. It also lies within the framework of the invention that the described principle can be advantageously applied when the laser beam incident into the acousto-optical modulator has high divergence, as is the case, for example, when the acousto-optical modulator in an arrangement according to Fig. 31 is to be arranged in the proximity of the focal point 201 or in arrangements wherein the laser has an especially great divergence. In Fig. 31, for example, the axis of the [ray] beam bundle emerging from the laser F_2 is intended to represent the position of the optimum Bragg angle for a specific frequency. In this case, the Bragg condition is met far more poorly for the one frequency for the rays at the edge of the ray bundle, for example of the lasers F_1 and F_3, than for the central rays of, for example, the laser F_2, and only a slight part of the radiation is deflected, which means low contrast for the modulator. When, however, a plurality of frequencies are simultaneously applied to the acousto-optical modulator and when these frequencies are selected such that they are optimum both for the outer as well as for the middle incident [ray] beam bundle with respect to the Bragg angle, the highest possible contrast derives and the highest possible difference in the power density arises on the processing surface between the radiation that is intended to produce a processing effect and the radiation that should not produce any processing effect.

Fig. 38 shows how a [flexible] smart arrangement of the components in the optical beam path can see to it that the laser [ray] beam bundles never perpendicularly impinge the optical surfaces. This prevents a part of the radiation

from being reflected from these surfaces back into the lasers. When energy proceeds back into a laser, an excitation occurs in the laser and the laser begins to oscillate in terms of the amplitude of the radiation that is output. The output power is thus no longer constant and patterns are formed in the process surface that can make the result unuseable. Fig. 38 shows the axial rays of two planes; the lasers, however, can also be arranged in one or more planes as long as the symmetry axis for the two axes that are shown is not used. For reasons of function, the acousto-optical modulator is already turned by the angle α_B. In order, however, to be certain that energy is not reflected back into the laser as a consequence of the changing ultrasound field, the modulator can be additionally turned by the angle γ, as shown in Fig. 38. Another possibility for avoiding oscillations of the laser is the insertion of one or more optical components at suitable locations in the beam path that only allow laser radiation to transmit in one direction. For example, what are referred to as Faraday isolators can be employed for this purpose, as described under Fig. 20 in the catalog of Spindler and Hoyer on page F2. Such isolators are not shown in the Figures.

Fig. 39 shows a lens 101 whose mount contains bores 87 that preferably surround the lens in a plurality of turns and have a coolant flowing through them. Given high-power arrangements, the absorption of the optical medium of the lenses [can] <u>cannot</u> be left out of consideration. Moreover, a slight part of the radiation is dispersed by every optical surface even given the best anti-[blooming] <u>reflection coated</u> and is absorbed by the mount parts. A cooling of the lens mounts is therefore meaningful. It has already been mentioned that materials having high thermal conductivity and low absorption such as, for example, sapphire are advantageous for the most stressed lenses. Sapphire also has the advantage that the lens surface does not scratch when cleaning due to the greater hardness of the material. One should also see to a good contacting of the optical medium with the mount. This is advantageously achieved by a metallization of the edge zone of the optical element and by a soldering 223 to the mount. Metallic solders [[...]] <u>contain</u> a better heat conduction than glass solders.

It is also possible to cool the critical component parts of the laser gun 23 and of the pump source 2 with the assistance of what are referred to as micro-channel coolers, as described in the article "Lasers in Material Processing" in the publication SPIE Proceedings, Vol. 3097, 1997.

Fig. 39a shows a section through an inventive mount 118 for the objective lens 61, 103, 112 that, for example, is secured with a thread to the tube body 95, 96 or to the mount 116 and is sealed with a seal 125. The objective lens can be glued into the mount or, preferably can be metallized at its edge and soldered into the mount. The mount can be provided with one or more bores 120 through which a protective atmosphere that comes from the interior of the optical unit 8 flows and, for example using a channel 119, is conducted via the side of the objective lens 61, 103, 112 pointing toward the processing surface in order to prevent a contamination of the objective lens by particles of material or by gases that are released during the processing.

Fig. 40 describes a further possibility for preparing fiber lasers or optical fibers, preferably single-mode fibers, for an arrangement in tracks and planes with small spacing. The fiber 28 or laser fiber 5 is ground on all sides at the last end to such an extent that a side length arises that is reduced to such an extent that the exit points of the laser radiation 13 lie at a required, slight spacing. In this case, the terminators 26, 94 can be omitted, and an especially simple structure derives. The surfaces that reside opposite can thereby proceed in pairs parallel to one another or at an angle, or one pair proceeds parallel and the other pair proceeds at an angle relative to one another, as was already described for the terminators under Figs. 9 and 10.

Fig. 40a shows a plan view onto, or a cross-section through the ground laser fiber. The cross-section can preferably be rectangular or quadratic; however, it can also have all other shapes.

Fig. 40b shows a side view of the fiber bundle wherein the fibers were processed similar to Fig. 40, so that the axes of the individual [ray] beam bundles 13 proceed nearly parallel.

Fig. 40c represents a side view of the fiber bundle wherein the fibers were processed wedge-shaped, so that the axes of the individual ray bundles 13 intersect outside the fiber bundle.

Fig. 40d again shows a side view of the fiber bundle wherein the axes of the individual fibers in fact proceed parallel but the exit faces of the individual fibers are arranged at different angles ε relative to the fiber axis, so that the axes of the individual ray bundles 13 intersect within the fiber bundle.

Fig. 41 shows how a receptacle with four tracks can be produced from ground fibers or laser fibers according to Fig. 40 and Fig. 40a, Fig. 40b, Fig. 40c, 40d. A receptacle in a plurality of planes is shown in broken lines in Fig. 41 in the form of two further planes. The receptacle is also not limited to four tracks and three planes; the laser outputs can be arranged in an arbitrary number of tracks and planes according to this principle. On the basis of a corresponding shaping when grinding the fibers, it is possible to determine the spacings between the exit points of the laser radiation 13. For example, the spacing can be implemented such that the laser radiation of the individual plans overlaps on the processing surface 81 such that only tracks derive or such that the individual tracks overlap so that only planes derive. The spacings between the exit points of the laser radiation 13, however, can also be selected such that the laser rays of all tracks and all planes overlap in a point on the processing surface. For this purpose, the fiber lasers or optical fibers can also be arranged in a bundle.

The principle of the described arrangement of laser outputs in a plurality of planes or in a plurality of tracks or in a plurality of tracks and in a plurality of planes or overlapping in a point also inventively applies to the laser rays incident on the processing surface 81. A plurality of tracks or a plurality of levels or a plurality of tracks and a plurality of levels of laser beams can likewise be arranged on the processing surface according to this ordering principle or the laser beams can be arranged overlapping in a point.

The arrangement according to Figs. 40, 40a, 40b, 40c, 40d and 41 is particularly suited for directly modulatable lasers. However, external modulators

relative to the table by an angle φ having the axis z' (Fig. 42c), which can also be utilized for determining the mutual spacing of the processing tracks. In the exemplary embodiments according to Figs. 4, 4b, 4c, 43, 44, the laser gun is turned around the axis of the tube 51, 95, 113 in order to vary the spacings between the processing tracks. Further, the table can be moved in the directions x, y, z and can be turned by an angle φ with the axis z. The material to be processed, for example one or more, what are referred to as "wafers" separated from a drawn semiconductor ingot, can be secured on the table 225 with clamp or suction devices (not shown). For example, fine, parallel tracks as needed, for example, for contacting photo-voltaic cells, can be incised into the semiconductor material with the laser energy in the individual processing points B_1 through B_n. However, fine bores can also be introduced into the semiconductor material or it can be cut with the laser in order, for example, to thus separate electrical circuits from one another. An inventive arrangement for removing the material 249 (Fig. 42c) eroded from the processing surface is attached close to the processing surface 81 for each processing track 224 separately or for a plurality of processing tracks 224 in common, the functioning of said arrangement being described in detail in Fig. 34. When the profiled rail with the terminators is turned relative to the table in order to modify the spacing between the processing tracks, it is inventively expedient to compensate the distortion of the pattern to be registered that arises due to the relative rotation by a pre-distortion of the pattern to be applied and/or to compensate it with a time control of the data stream. On the basis of the turning, it is also possible to intentionally provide different line spacings given relative motions in x-direction and in y-direction. For contacting of the photo-voltaic cells, for example, two different line patterns are required: a first pattern wherein the incised lines following the metallization produce the contact to the semiconductor material should have spacings of a few millimeters between the individual lines and should, for example, proceed in the x-direction. Further, what are referred to as bus bars are required that proceed at a right angle relative to the contact lines and connect these to one another. These lines forming the bus

bars should, for example, proceed in the y-direction and lie close to one another so that they act like a closed band following the metallization. Inventively, such a pattern can be very simply manufactured in that the profiled rail with the terminators is turned to such an extent until the desired pattern results. Due to the parallel arrangement of a plurality of fiber laser outputs, the time required for the processing can be considerably shortened; for example, ten laser outputs can be employed in parallel for the incising of the photo-voltaic elements 10, this increasing the output by the factor of 10.

The described arrangement for cutting and incising is not only suitable for processing semiconductor materials but can be employed for all materials wherein the precise production of patterns is important such as, for example, in manufacturing printing forms.

Fig. 42a and the corresponding sectional view of Fig. 42b show how the terminators 26 of the individual fiber lasers F_a through F_n are secured. The profiled rail 256 is secured to a carrier 260 with connections 261, the carrier potentially being, for example, the arm of a robot. The terminators 26 are accepted in mounts 257 and fixed with screw 259. The mounts 257 are provided with a profile mating with the profiled rail 256, are placed in a row onto the profiled rail 256, are set at predetermined intervals "A" from one another and are fixed with the screws 259. Due to an inventively small structure of the terminators 26 and of the mounts 257, a very slight spacing"A" is possible. The profiled rail with the terminators can be conducted across the processing surface with the robot for the purpose of processing the material, as shown in Fig. 42 and described in detail. The required movements for producing the processing tracks can be executed by the table 225 described in Fig. 42 that can also be carried out by the arm of the robot. Preferably, the arm of the robot can also undertake a rotatory motion around the rotational axis z' of the arrangement that is approximately parallel to the axis of the terminators. With this rotation and a relative displacement between the arm of the robot and the table 225, it is possible to modify the spacing of the processing tracks generated on the processing surface

81 and to preferably set them smaller than corresponds to the dimension "A" that has been set.

Fig. 42c indicates an example of the robot that can be constructed, for example, of components of Montech-Deutschland GmbH, Postfach 1949, 79509 Lörrach. A horizontal-linear unit 263 is secured on a stand system "Quickset" 262, the unit 263 in turn accepting a vertical-linear unit 264 having a rotatory drive 265. The actual robot arm 260 is seated at the rotatory drive, the profiled rail 256 being secured to the arm 260 with the connection 261. Another horizontal-linear unit is possible but not shown.

The various motion directions of the table 225 can be realized with the same element, whereby the motion directions can also be partly allocated to the table and partly to the profiled rail. The housing for the acceptance of individual components, the cooling system, the control for the lasers, the pump sources for the fiber lasers, and the terminators 26, 94 are shown, the arrangement for removing the material eroded from the processing surface and the machine control for the drives are not shown in the Figures.

Fig. 43 shows a further flatbed arrangement with the inventive laser radiation source. The material to be processed with the processing surface 81 is located on a table 247 that is seated on guides 251 and can be moved in the feed direction u precisely with a spindle 252. The spindle 252 is placed into rotation by a motor 254 via a gearing 253 that is driven proceeding from a control electronics 255. The laser radiation emerging from the laser gun 23 generates the processing points B_1 through B_n in an intermediate image plane 228 (not shown here) that, for example, is shown in Fig. 44. The laser radiation is conducted via deflection mirror 241 and an optics 242 belonging to an optical unit onto a rotating mirror 243 that, for example, can have one mirror face that, however, can also be designed as a rotating mirror having a plurality of mirror faces and that is placed into a rotatory motion by a motor 244 driven proceeding from the control electronics 255. The rotating mirror 243 steers the laser radiation over the processing surface line-by-line in arrow direction v. An optics 245 belonging to

the optical device is located between the rotating mirror and the processing surface, the job of the optics 245 being to generate a sharp processing spot on the processing surface over the entire line length, this processing spot being potentially composed of a plurality of processing points B_1' through B_n' that are shown in Fig. 43. As a result of the rotation of the rotating mirror, the processing points generate processing tracks 224 on the processing surface 81 as shown, for example, in Figs. 35, 36 and 37. Preferably, a long deflection mirror 246 is provided between the processing surface 81 and the optics 245 in order to achieve a compact structure. The laser gun 23 is preferably turned in the prism 248 such that the processing tracks have the desired spacing from one another on the processing surface, this being shown in Fig. 35. The fixing of the laser gun can occur with a strap retainer (not shown). An inventive arrangement 249 for removing the material eroded from the processing surface is attached close to the processing surface 81 over the entire line length, the arrangement 249 being capable of being provided with a glass plate 230 over the entire length and being shown in greater detail in Fig. 43b. In Fig. 43, a laser gun with the lenses 102 and 103 according to Fig. 4b and a beam path illustrated in Fig. 20 can be provided; however, all other types of inventive laser guns can also be used. Further, a plurality of laser radiation sources can be attached in such a flat bed arrangement in order to speed the processing procedure up. Inventively, a second laser radiation source with the corresponding optics and the arrangement 249 for removing the material eroded from the processing surface can be attached opposite the illustrated arrangement such that further processing tracks derive on the processing surface.

It lies within the framework of the invention that the rotating mirror can also be replaced by an oscillating mirror. It also lies in the scope of the invention that the rotating mirror can be replaced by two oscillating mirrors, whereby the oscillatory direction of the one mirror, called "mirror u", lies on the processing surface 81 in the direction referenced u, and whereby the oscillating direction of

the other mirror called “mirror v”, lies on the processing surface 81 in the direction referenced v.

An arrangement having oscillating mirrors is especially well-suited for fast incising of photo-voltaic cells, as was described in detail under Fig. 42. The cell to be incised is placed onto the table 247 with, for example, a loading device that is not shown in Fig. 43 and is brought into the correct position. The laser gun 23 is turned such that the desired spacings in the processing tracks arise in the two processing directions u and v. In a first processing event, for example, mirror u draws the contact lines, whereas mirror v undertakes the correct positioning of the contact line packets. In a second processing event, mirror v draws the bus bars, whereas mirror u undertakes the correct positioning of the line packets. In these processing events, the photo-voltaic cell is not moved. It lies within the scope of the invention that the table 247 can be replaced by a magazine (not shown) wherein a specific number of photo-voltaic cells are delivered for processing, that the processing of the respective cell occurs directly in the magazine, and that the processed cell is automatically removed from the magazine after the processing and is transferred into a second magazine, whereby the next, unprocessed cell for processing moves forward to take the place of the removed cell.

As a result of the extremely high beam quality of the laser radiation source that derives due to the fiber laser working [refraction] <u>diffraction</u>-limited, a nearly parallel laser beam bundle can be generated, as shown in Fig. 43 between the optics 242 and rotating mirror 243 and as can also be seen in Fig. 4 between the lenses 57 and 61. Consequently, it is also possible to remove the optics 245, the rotating mirror 243 and the deflection mirror 246 in Fig. 43 and replace them by a deflection mirror (not shown) that deflects the nearly parallel laser beam bundle emerging from the optics 242 in the direction of the processing surface 81 and onto an objective lens (not shown) having a short focal length that is implemented similar to the objective lenses 61, 103 or 112.

The deflection mirror and the objective lens are inventively combined with one another to form a unit and slide back and forth on a guide rail (not shown) in

the direction v, so that a number of parallel processing tracks corresponding to the number of channels in the laser radiation source are registered on the processing surface (81) similar to previously with the rotating mirror 243 and the optics 245.

Inventively, the guide rail is implemented as a bearing having very low friction, for example as an air bearing or as a magnetic bearing. The drive of the unit composed of the objective lens and the deflection mirror in the direction v and back respectively occurs with a thrust into the corresponding direction that, for example, is carried out by a preferably contact-free electromagnetic system, whereby the energy acquired from the deceleration of the moving unit is partially re-employed for the drive. Parts of the guide rail, deflection mirror and objective lens are, for example, accommodated in a closed space that contains windows for the entry and the exit of the laser radiation and can be evacuated in order to reduce frictional losses. The drive and guide rail represent a linear drive for the unit composed of the objective lens and the deflection mirror.

It lies within the framework of the invention that the respective, true position of the moving unit can be determined for correction purposes via, for example, an optical reference track. An arrangement 249 serves for the removal of the material eroded from the processing surface 81. The advantage of such an arrangement is that it can be very cost-beneficially realized for long path lengths and high resolutions, and that it can be set to various formats by displacement of the one and/or other drive. A plurality of such units can also be arranged in parallel in order to increase the processing speed.

Fig. 43a shows a simplification of the arrangement according to Fig. 43 in that the two lenses 102 and 103 have been removed from the laser gun. Given a corresponding spacing of the laser gun from the deflection mirror 241, the divergent laser ray bundles emerging from the lens 101 are focused onto the processing surface 81 with the lenses 241 and 245 and generate the processing points B_1 through B_n that are identical to the processing points B_1' through B_n' in this case.

Fig. 43b shows the arrangement 249 for removing the material eroded from the processing surface in greater detail. The functioning has been described in detail in Fig. 34.

Fig. 44 shows a hollow bed arrangement for processing material with the inventive laser radiation source. Hohlbett arrangements are known; for example, two arrangements having hollow bed are described in the publication "Der Laser in der Druckindustrie" by Werner Hülsbuch, Verlag W. Hülsbusch, [Constanc] Konstanz, pages 461 and 562. The material to be processed with the processing surface 81 is located in a cylinder or, preferably, a part of a cylinder 236 having the radius R. This arrangement is referred to as a hollow bed on whose axis a bearing 229 with a rotating mirror 233 is arranged. The rotating mirror can, for example, have one mirror face but can also be designed with a plurality of mirror faces and can be placed into rotation by a motor 234 and be arranged on a carriage (not shown) displaceable in the direction of the cylinder axis relative to the cylinder 236. An optics 231 belonging to an optical device and a mirror 232 are arranged as well on the carriage (not shown) in the proximity of the processing surface 81. Further, a deflection mirror 227 and the laser gun 23 as well as an arrangement 235 - close to the processing surface 81 - for removing the material eroded from the processing surface, which is described in greater detail in Fig. 34, are located on the carriage. The ray bundles 226 emerging from the laser gun generate processing points B_1 through B_n in an intermediate image plane 228 that are transmitted onto the processing surface 81 with the deflection mirror 227, the mirror optics 231, 232 and the rotating mirror 233. Here, they generate the processing points B_1' through B_n'. The processing points B_1' through B_n' that form the processing spot generate processing tracks 224 (Figs. 35, 36 and 37) across the entire line length that are registered sharply focused over the entire line length as a result of the constant radius of the hollow bed. The advantage of the illustrated arrangement is that a compact structure can be achieved. In particular, the illustrated arrangement enables a small angle δ between the axis of the ray bundle incident onto the rotating mirror 233 and the ray bundle that is reflected by the

rotating mirror onto the processing surface, which is desirable for low distortion in the recording geometry on the processing surface. The laser gun is preferably seated in a prism (not shown) and is secured with a fastening strap (likewise not shown). The laser gun can be turned around its axis and can be displaced in the axial direction. As a result of the rotation, the distance between the processing tracks can be modified, this being shown in Fig. 35. The spacing from the processing surface can be modified by the displacement. An inventive arrangement 235 for removing the material eroded from the processing surface is attached over the entire line length close to the processing surface 81, the arrangement 235 being capable of being designed similar to what is shown in Fig. 43b, whereby it is implemented in curved fashion corresponding to the radius R of the cylinder 236 and can be provided with a curved glass plate 237 (not shown) over the entire length, the functioning thereof having been described in detail under Fig. 34. In Fig.44, a laser gun having the lenses 102 and 103 according to Fig. 4b and a beam path shown in Fig. 20 are provided. However, all other types of the inventive laser gun can be utilized. Further, a plurality of laser radiation sources can also be attached in such a hollow bed arrangement in order to speed the processing event up. For example, a second rotating mirror and a second laser radiation source as well as a second arrangement 235 for removing the material eroded from the processing surface can be attached opposite the illustrated arrangement such that further processing tracks derive on the processing surface.

Fig. 44a shows a simplification of the arrangement according to Fig. 44, in that the two lenses 102 and 103 were removed from the laser gun. Given a corresponding spacing of the laser gun from the deflection mirror 227, the divergent laser ray beams emerging from the lens 101 are focused onto the processing surface 81 with the lens 231 and generate the processing points B_1 through B_n that are identical to the processing points B_1' through B_n' in this case.

[

]While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not

restrictive in character, it being understood that only the preferred embodiment has been shown and described and that all changes and modifications that come within the spirit of the invention are desired to be protected.

Abstract

In a laser radiation source, preferably for processing material, as well as to an arrangement for processing material with the laser radiation source and to the operation thereof, for achieving a high power density and energy, the laser radiation source comprises a plurality of [directly modulatable] diode-pumped fiber lasers whose outputs are arranged in a bundle. The laser radiation emerging from the outputs of the fiber lasers is merged and bundled with an optical unit such that the laser radiation is incident onto a processing surface at a processing spot .

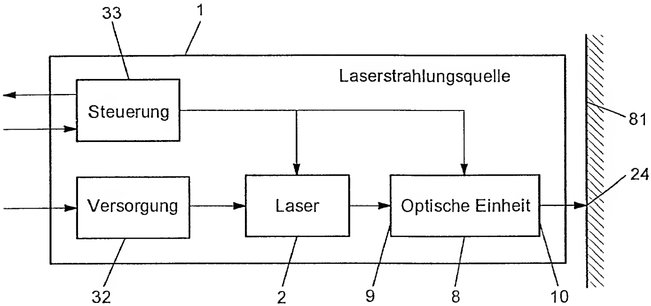


Fig. 1

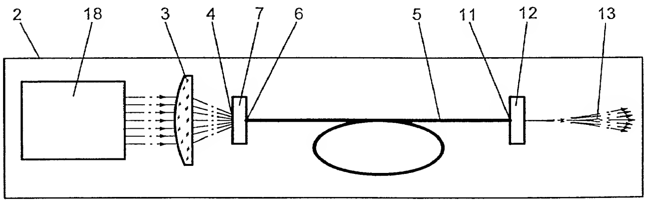


Fig. 2

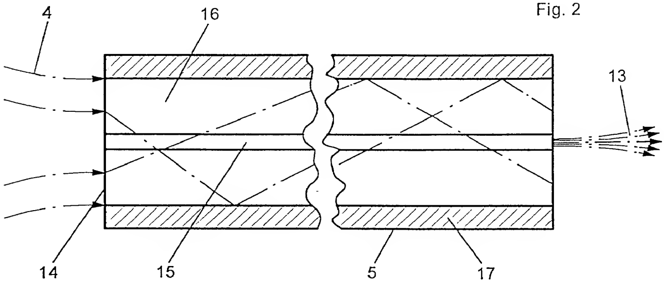


Fig. 2a

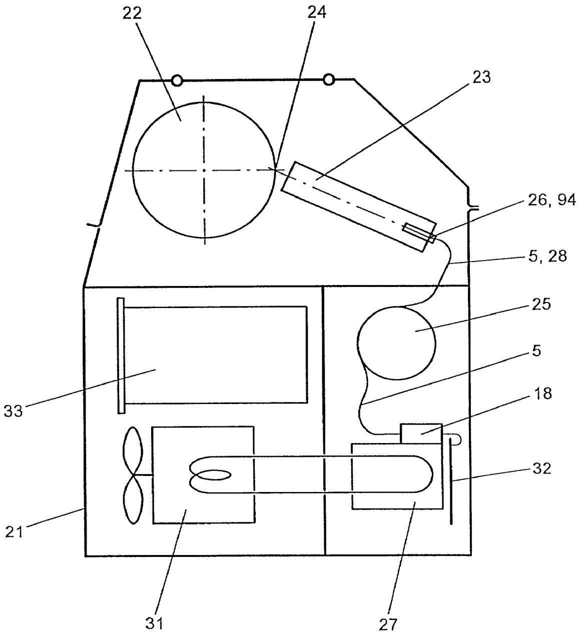
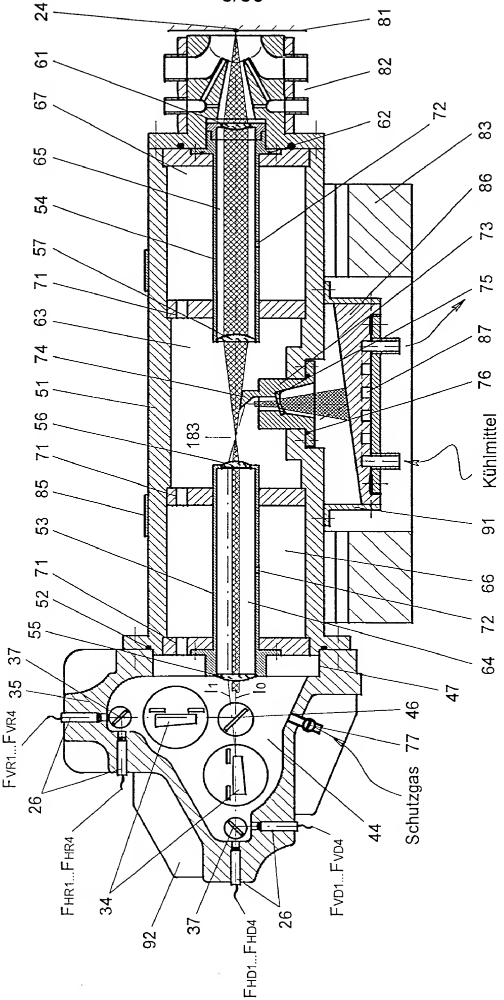
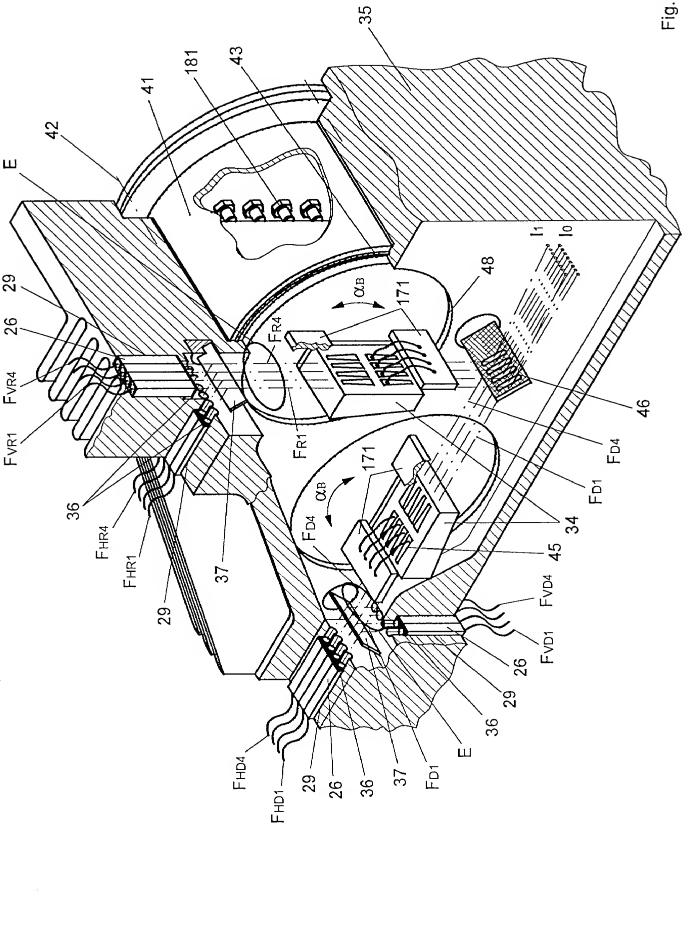


Fig. 3



24
61
67
65
54
57
71
63
74
51
56
71
85
53
71
52
55
37
35
$F_{VR1} \ldots F_{VR4}$
26
$F_{HR1} \ldots F_{HR4}$
34
92
37
$F_{HD1} \ldots F_{HD4}$
26
$F_{VD1} \ldots F_{VD4}$
Schutzgas
44
77
46
47
64
72
66
91
Kühlmittel
76
87
75
73
86
83
72
62
82
81
183
l_1
l_0

Fig. 4



E
42
41
181
43
35
29
26
F_{VR4}
F_{VR1}
36
F_{HR4}
F_{HR1}
29
37
F_{R4}
α_B
171
48
F_{R1}
46
F_{D4}
F_{D1}
34
l_1
l_0
171
α_B
F_{D4}
45
F_{VD4}
F_{VD1}
26
29
36
E
F_{D1}
37
36
26
29
F_{HD4}
F_{HD1}

Fig. 4a

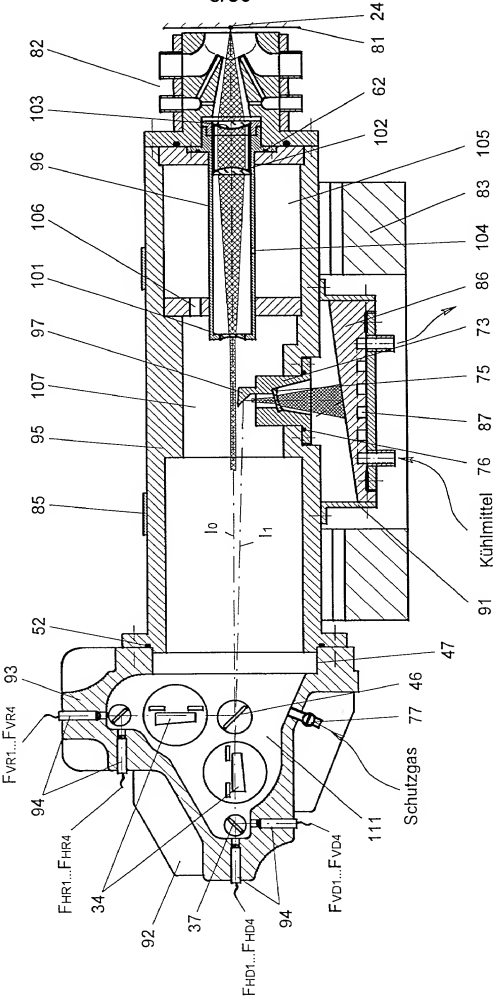

24
81
82
62
103
102
96
105
83
106
104
101
86
97
73
107
75
95
87
76
85
Kühlmittel
l_0
l_1
91
52
47
93
46
77
$F_{VR1}...F_{VR4}$
Schutzgas
94
111
$F_{HR1}...F_{HR4}$
34
$F_{VD1}...F_{VD4}$
37
94
92
$F_{HD1}...F_{HD4}$

Fig. 4b

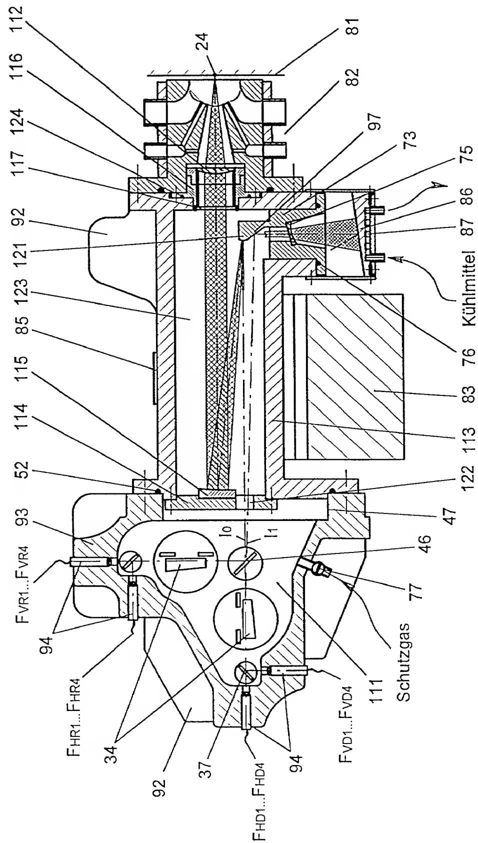

112
116
124
117
92
121
123
85
115
114
52
93
FVR1...FVR4
94
FHR1...FHR4
34
92
37
FHD1...FHD4
94
FVD1...FVD4
111
Schutzgas
77
46
I0
I1
47
122
113
83
76
Kühlmittel
87
86
75
73
97
82
81
24

Fig. 4c

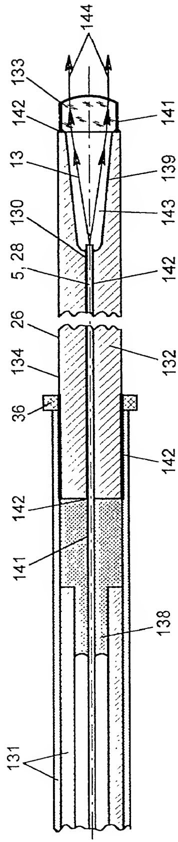

144
133
142
141
13
139
130
143
5, 28
142
26
134
132
36
142
142
141
138
131

Fig. 5

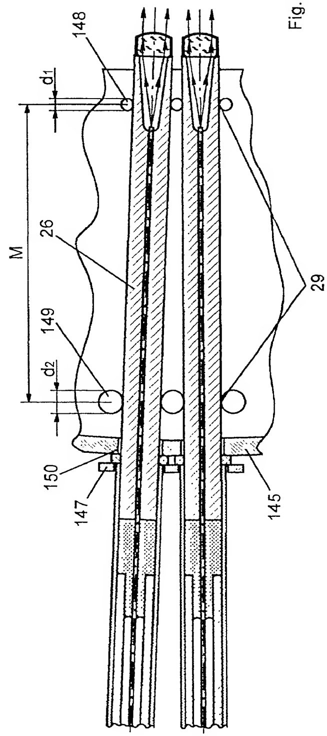

148
d1
M
26
149
d2
29
150
147
145

Fig. 5a

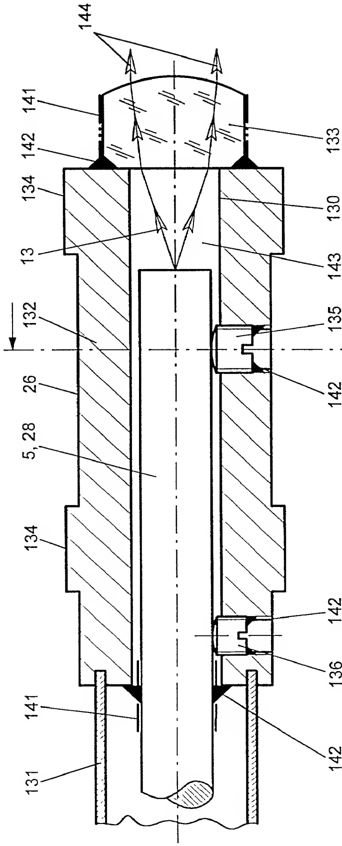

144
141
142
134
13
132
26
5, 28
134
141
131
133
130
143
135
142
142
136
142

Fig. 5b

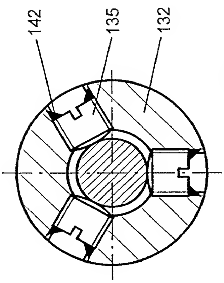

142
135
132

Fig. 5c

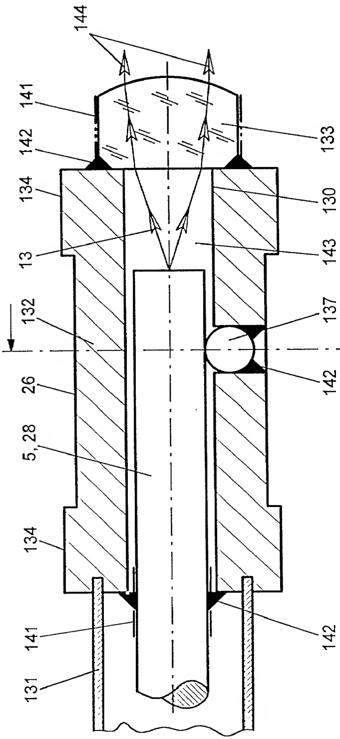

144
141
142
134
13
132
26
5, 28
134
141
131
133
130
143
137
142
142

Fig. 6

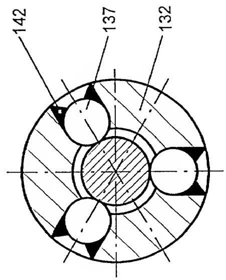

142
137
132

Fig. 6a

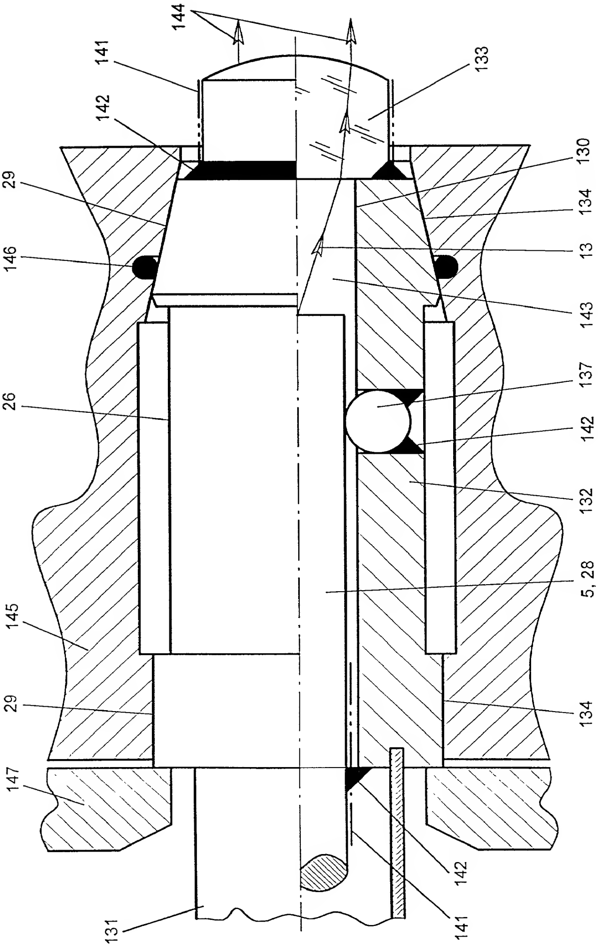

144
141
133
142
130
29
134
146
13
143
137
26
142
132
5, 28
145
29
134
147
142
131
141

Fig. 7

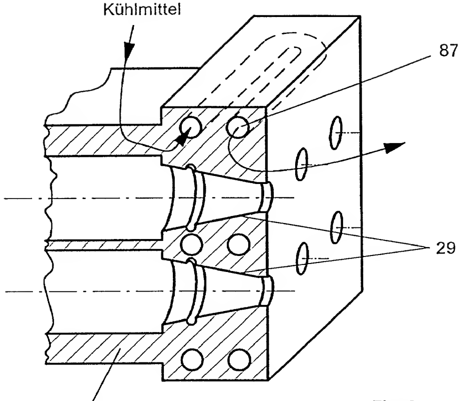


Fig. 8

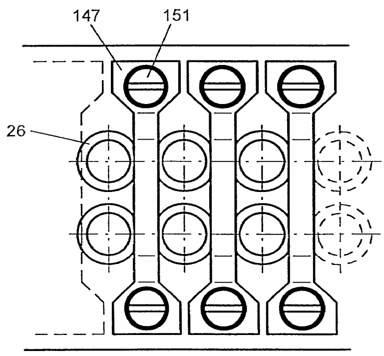


Fig. 8a

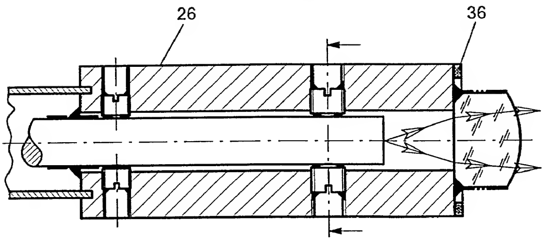


Fig. 9

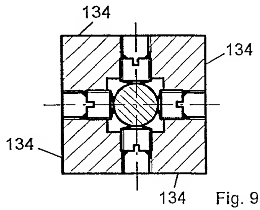


Fig. 9a

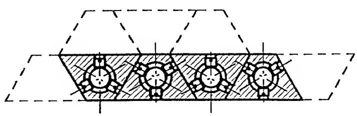


Fig. 11

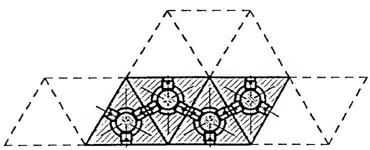


Fig. 11a

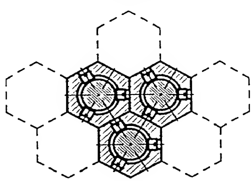


Fig. 12

09/786742

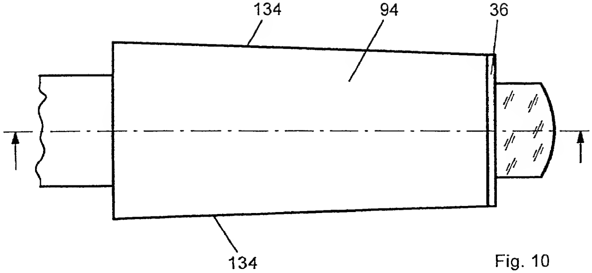


Fig. 10

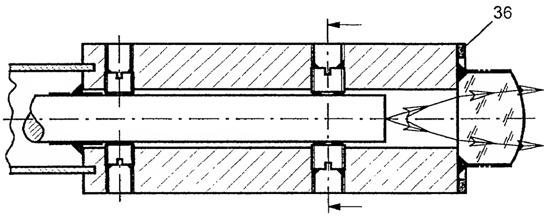


Fig. 10a

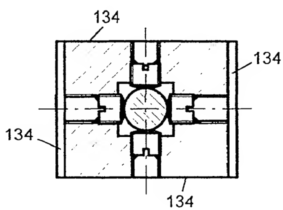


Fig. 10b

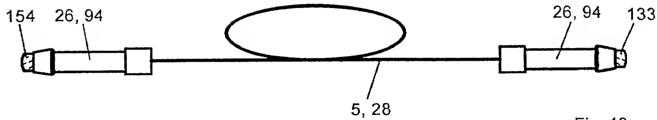


Fig. 13

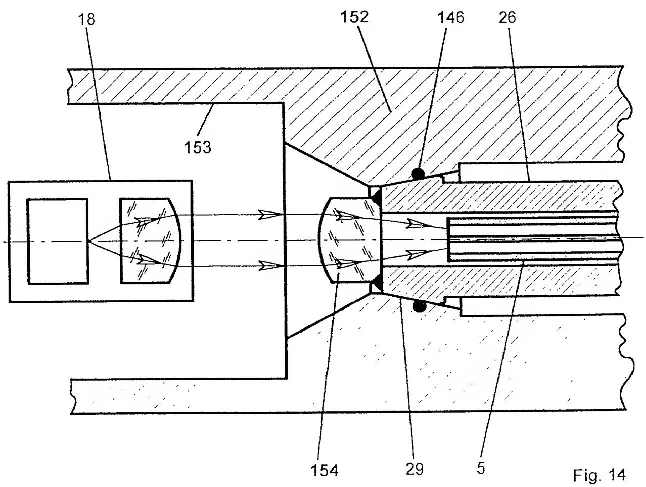


Fig. 14

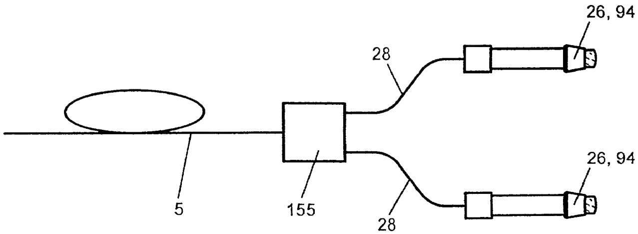


Fig. 15

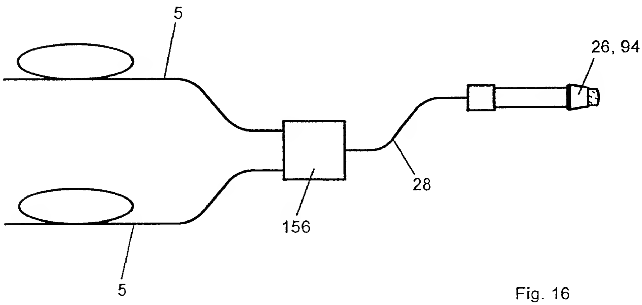


Fig. 16

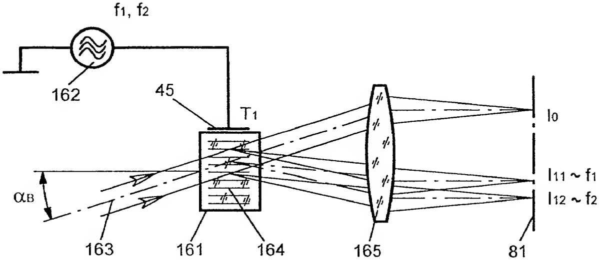

f1, f2
162
45
T1
Io
I11 ~ f1
I12 ~ f2
αB
163
161
164
165
81

Fig. 17

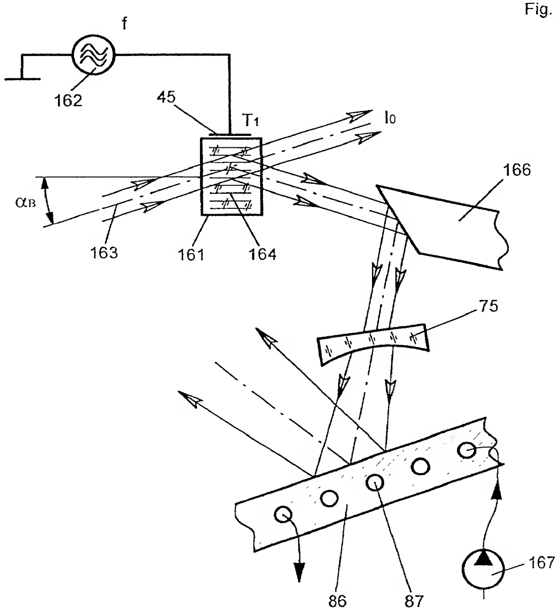

f
162
45
T1
Io
166
αB
163
161
164
75
167
86
87

Fig. 18

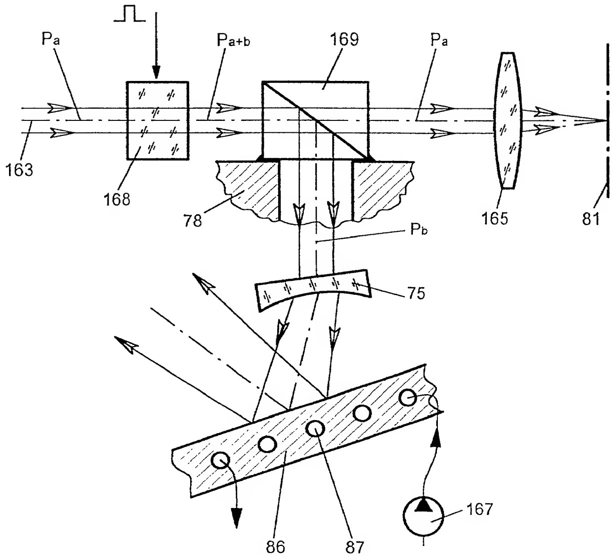


Fig. 18a

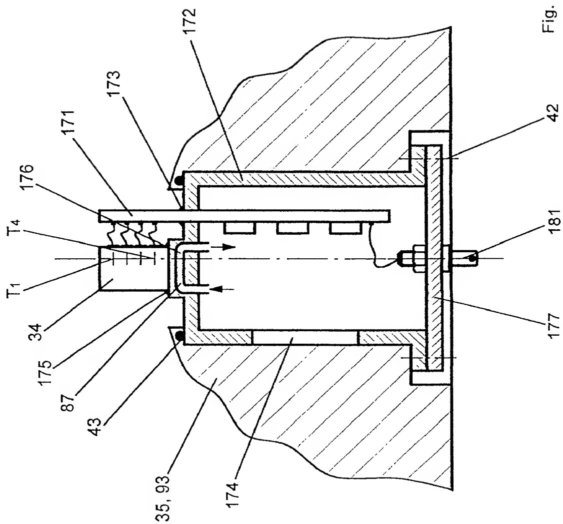


Fig. 19a

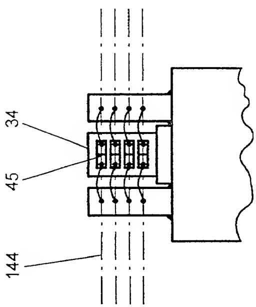


Fig. 19

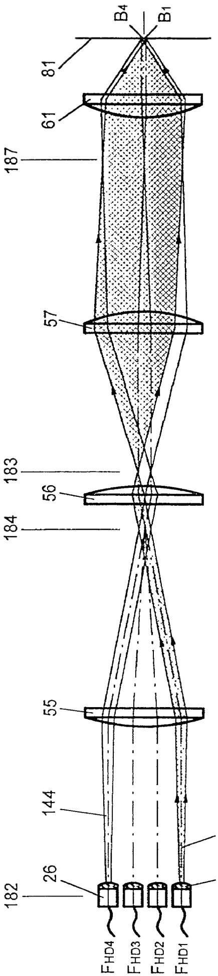


Fig. 20

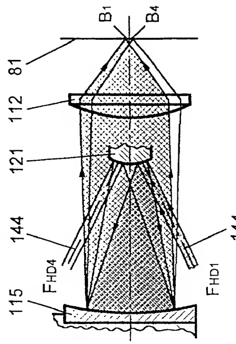


Fig. 22

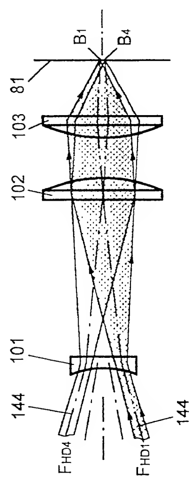


Fig. 21

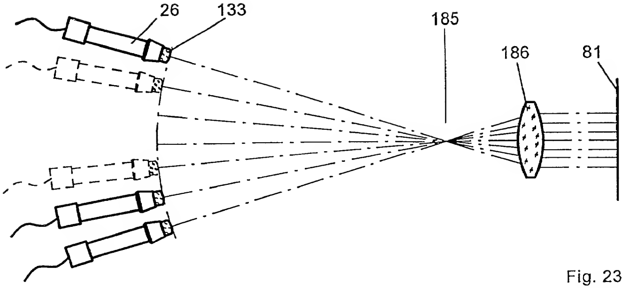


Fig. 23

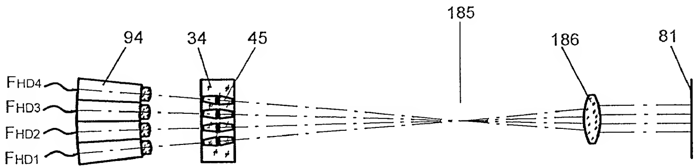


Fig. 24

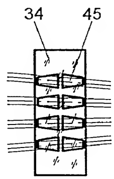


Fig. 24a

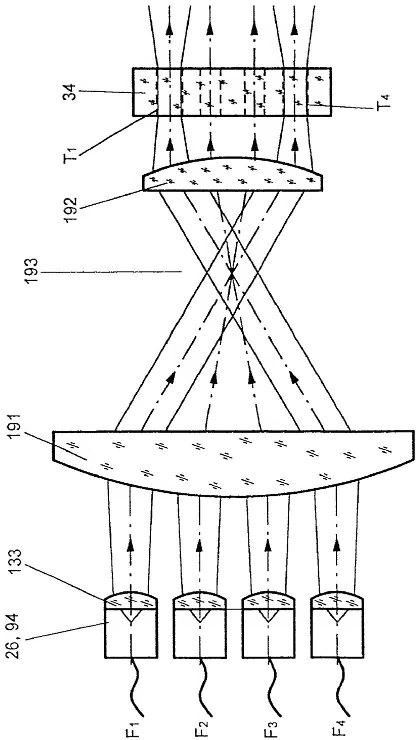


Fig. 25

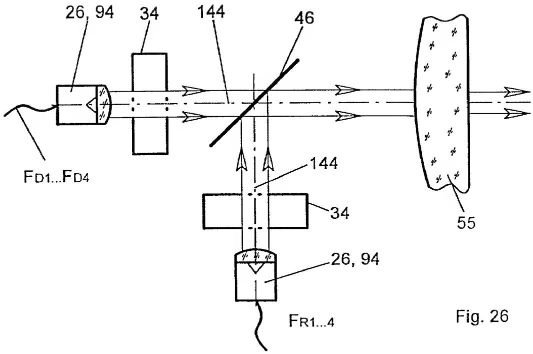


Fig. 26

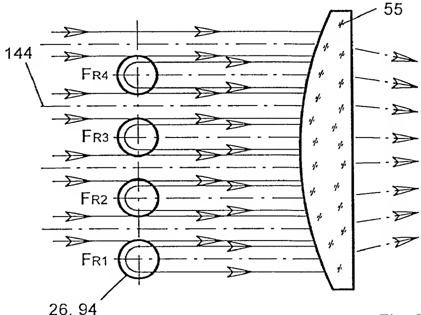


Fig. 26a

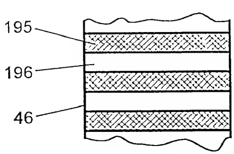


Fig. 27

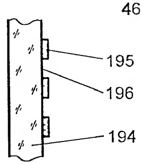


Fig. 27a

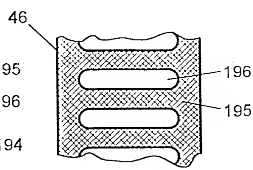


Fig. 27b

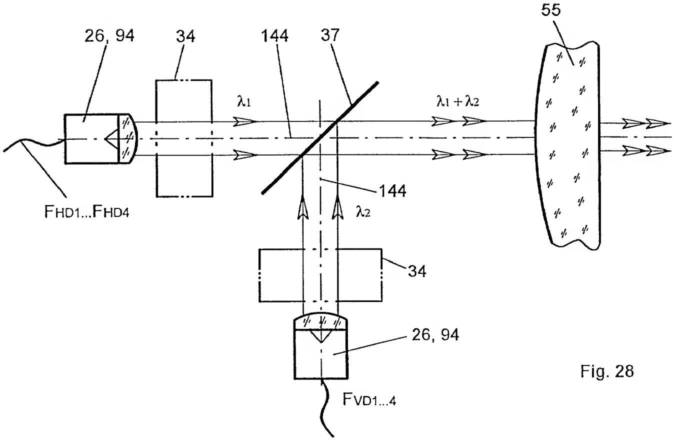


Fig. 28

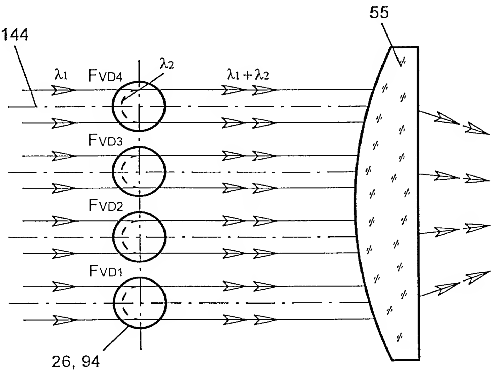


Fig. 28a

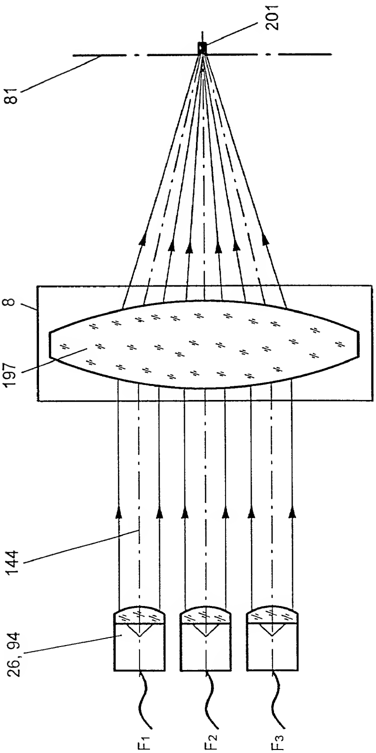


Fig. 31

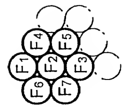


Fig. 30

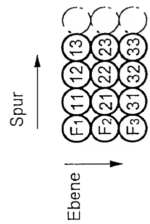


Fig. 29

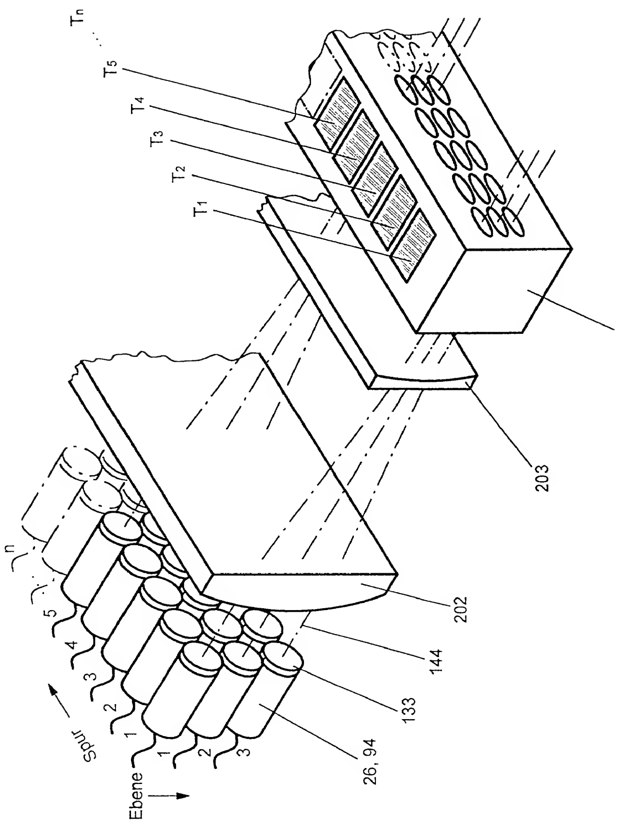


Fig. 32

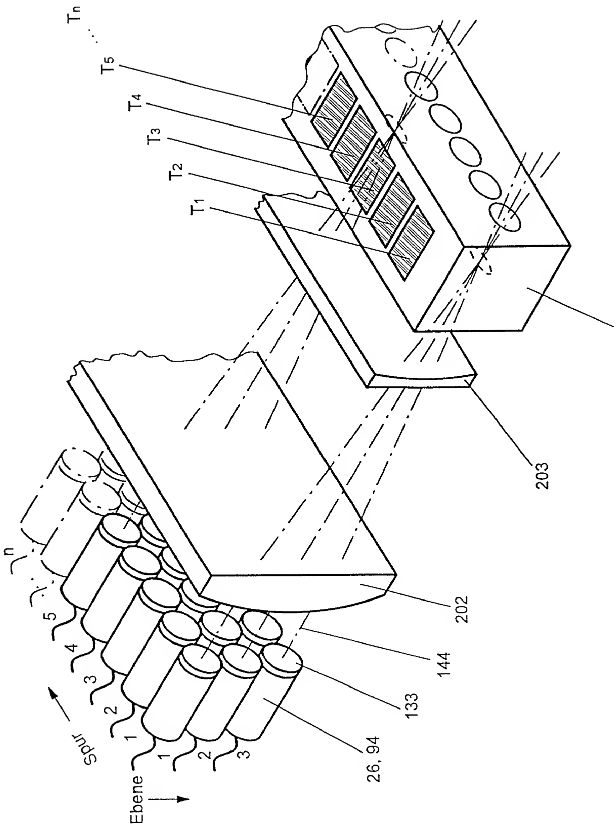


Fig. 33

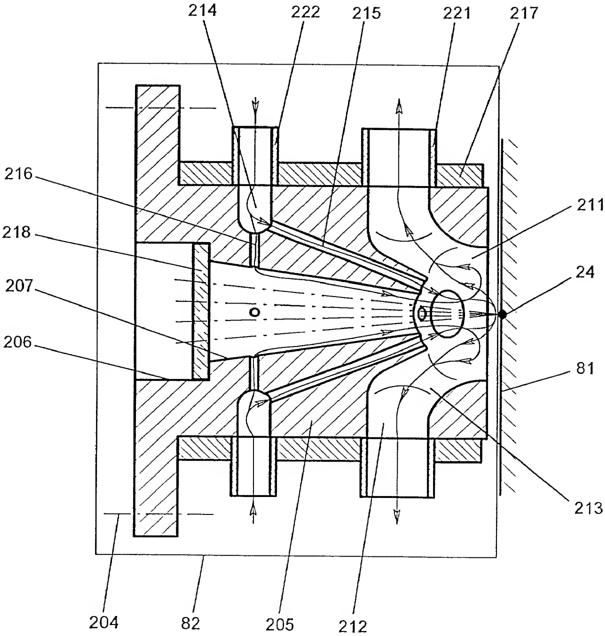


Fig. 34

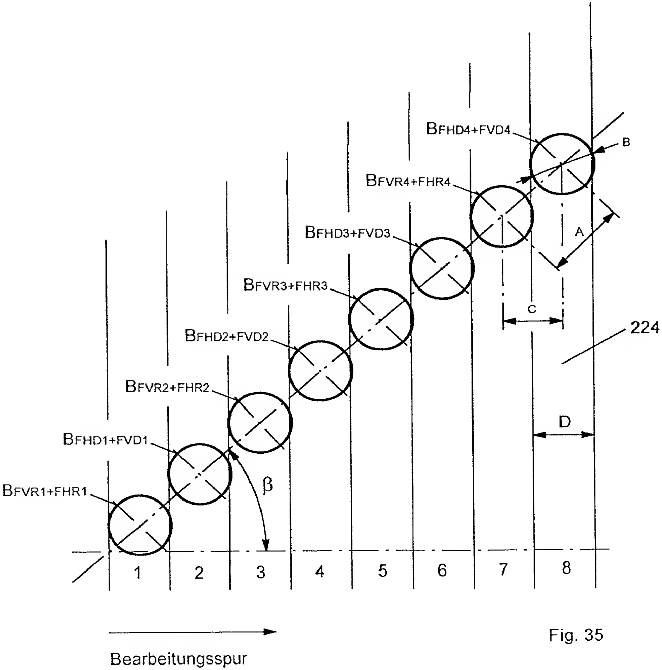

BFHD4+FVD4
B
BFVR4+FHR4
A
BFHD3+FVD3
BFVR3+FHR3
C
224
BFHD2+FVD2
BFVR2+FHR2
D
BFHD1+FVD1
β
BFVR1+FHR1
1
2
3
4
5
6
7
8
Bearbeitungsspur

Fig. 35

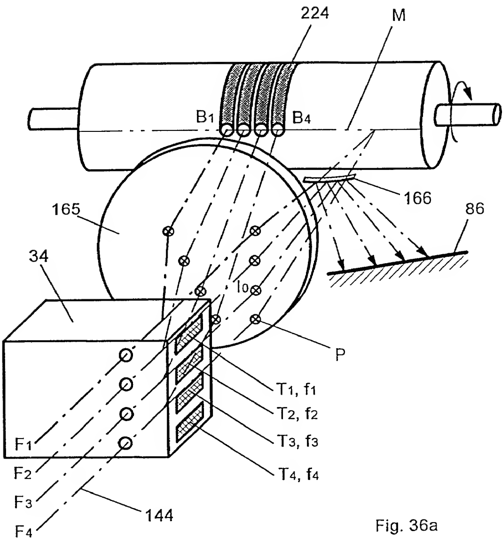


Fig. 36a

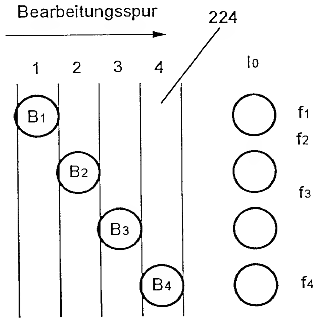


Fig. 36

09/786742

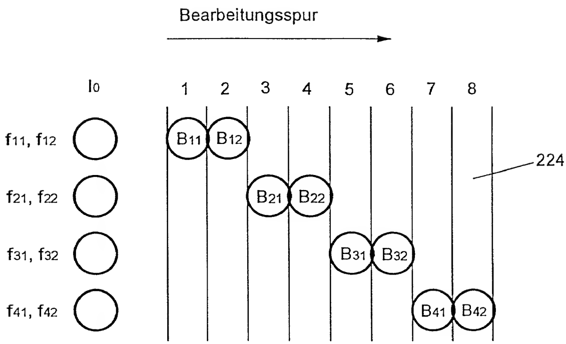


Fig. 37

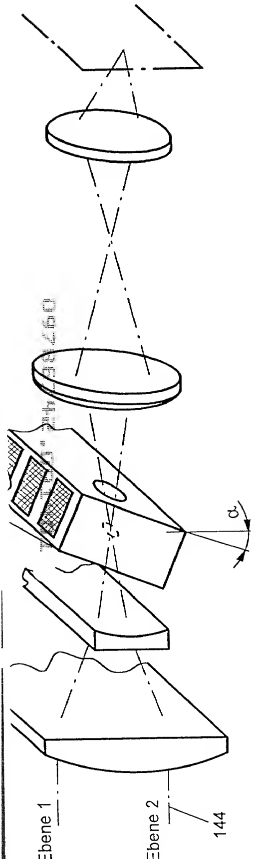


Fig. 38

39

119

12

39a

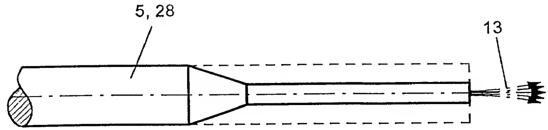


Fig. 40

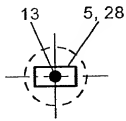


Fig. 40a

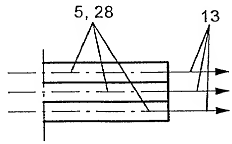


Fig. 40b

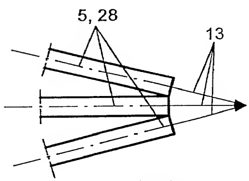


Fig. 40c

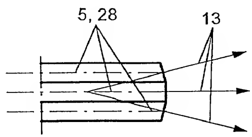


Fig. 40d

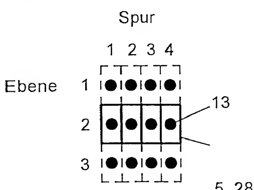


Fig. 41

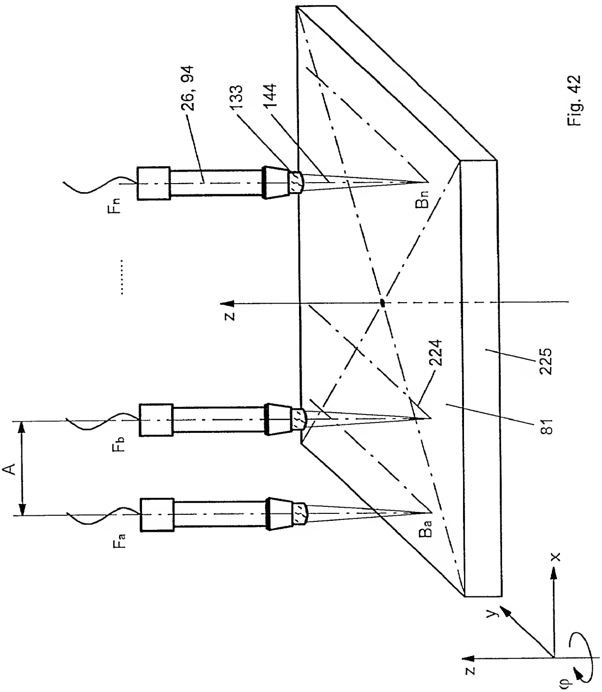


Fig. 42

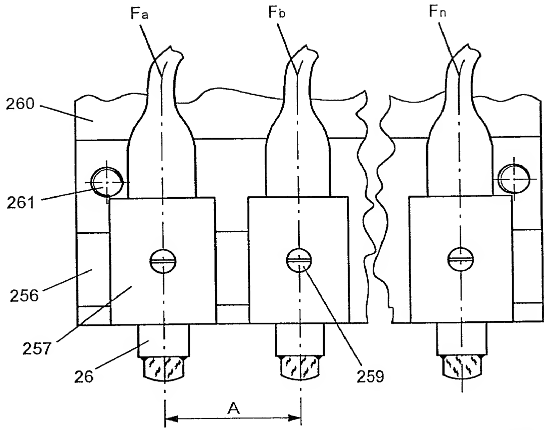


Fig. 42a

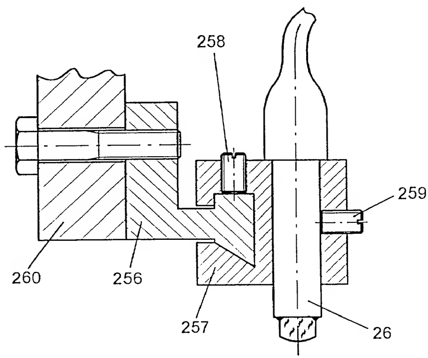


Fig. 42b

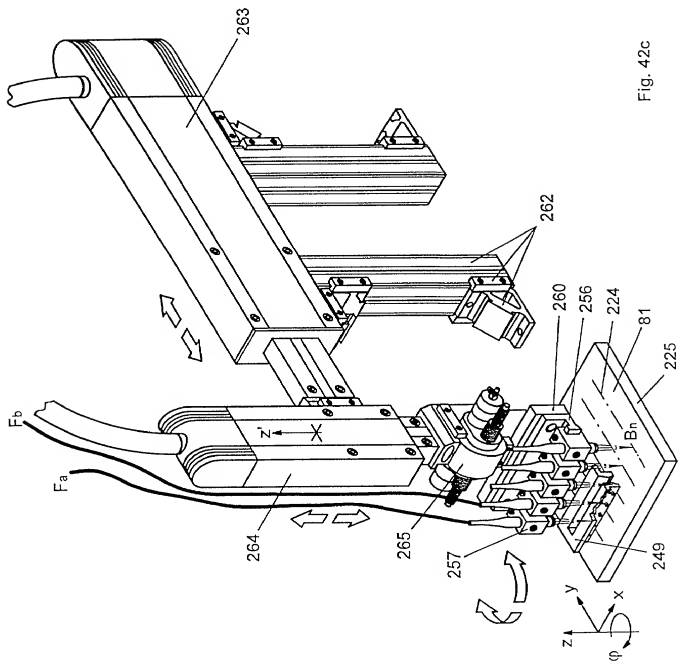


Fig. 42c

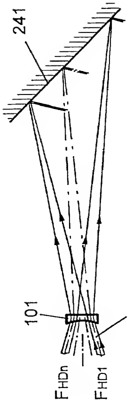


Fig. 43a

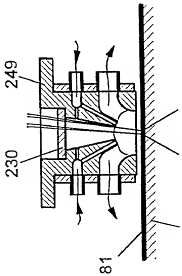


Fig. 43b

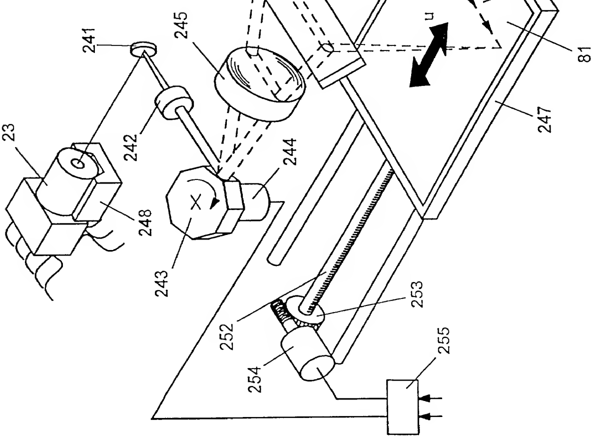


Fig. 43

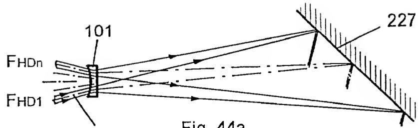


Fig. 44a

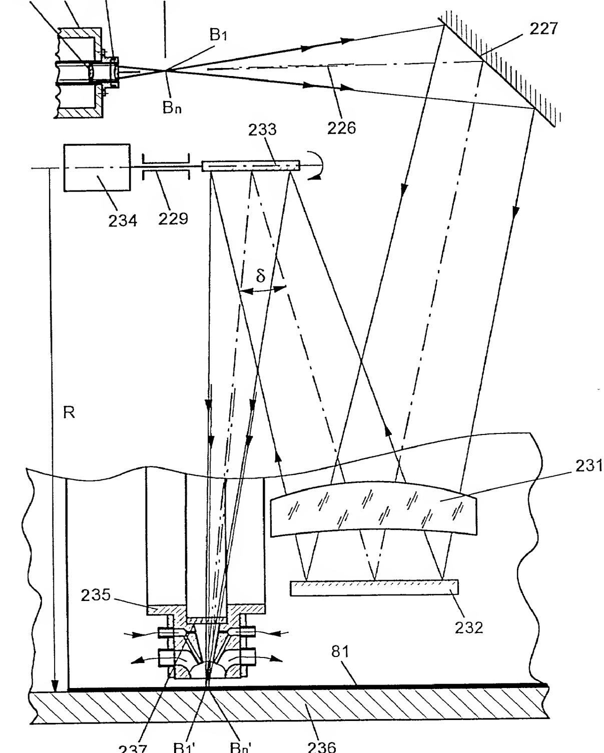


Fig. 44

COMBINED DECLARATION FOR PATENT APPLICATION AND POWER OF ATTORNEY (Includes Reference to PCT International Applications) **PCT/DE99/02721**	ATTORNEY'S DOCKET NUMBER **P01,0032**

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name, I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

"LASER RADIATION SOURCE"

the specification of which (check only one item below):

☐ is attached hereto.

☐ was filed as United States application Serial No. ______________

on ______________,

and was amended

on ______________(if applicable).

☒ was filed as PCT international application

Number **PCT/DE99/02721**

on **01 September 1999**,

and was amended under PCT Article 19

on ______________(if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

PRIOR FOREIGN/PCT APPLICATION(S) AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. 119:

COUNTRY (if PCT indicate "PCT")	APPLICATION NUMBER	DATE OF FILING (day, month, year)	PRIORITY CLAIMED UNDER 35 USC 119
GERMANY	**198 40 926.5**	**08 September 1998**	■ YES ☐ NO
			☐ YES ☐ NO
			☐ YES ☐ NO
			☐ YES ☐ NO
			☐ YES ☐ NO

Combined Declaration For Patent Application and Power of Attorney (Continued)

(Includes Reference to PCT International Applications) PCT/DE99/02721

ATTORNEY'S DOCKET NO.

P01,0032

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) or PCT international application(s) designating the United States of America that is/are listed below and, insofar as the subject mater of each of the claims of this application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of Title 35, Untied States Code, §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occurred between the filing date of the prior application(s) and the national or PCT international filing date of this application:

PRIOR U.S. APPLICATIONS OR PCT INTERNATIONAL APPLICATIONS DESIGNATING THE U.S. FOR BENEFIT UNDER 35 U.S.C. 120:

U.S. APPLICATIONS		STATUS (Check one)		
U.S. APPLICATION NUMBER	U.S. FILING DATE	PATENTED	PENDING	ABANDONED

PCT APPLICATIONS DESIGNATING THE U.S.					
PCT APPLICATION NO	PCT FILING DATE	U.S. SERIAL NUMBERS ASSIGNED (if any)			

POWER OF ATTORNEY: And I hereby appoint all Attorneys identified by United States Patent & Trademark Office customer number 26574, who are all members of the firm of Schiff Hardin and Waite.

Send Correspondence to:

SCHIFF HARDIN & WAITE
Patent Department
6600 Sears Tower, Chicago, Illinois 60606
CUSTOMER NO. 26574

Direct Telephone Calls to:
312/258-5500
Ext. 5786

201	FULL NAME OF INVENTOR	FAMILY NAME Jürgensen	FIRST GIVEN NAME Heinrich	SECOND GIVEN NAME
	RESIDENCE & CITIZENSHIP	CITY Raisdorf	STATE OR FOREIGN COUNTRY GERMANY	COUNTRY OF CITIZENSHIP GERMANY DEX
	POST OFFICE ADDRESS	POST OFFICE ADDRESS Dutschfeldredder 22	CITY 24223 Raisdorf	STATE & ZIP CODE/COUNTRY GERMANY
202	FULL NAME OF INVENTOR	FAMILY NAME	FIRST GIVEN NAME	SECOND GIVEN NAME
	RESIDENCE & CITIZENSHIP	CITY	STATE OR FOREIGN COUNTRY	COUNTRY OF CITIZENSHIP
	POST OFFICE ADDRESS	POST OFFICE ADDRESS	CITY	STATE & ZIP CODE/COUNTRY
203	FULL NAME OF INVENTOR	FAMILY NAME	FIRST GIVEN NAME	SECOND GIVEN NAME
	RESIDENCE & CITIZENSHIP	CITY	STATE OR FOREIGN COUNTRY	COUNTRY OF CITIZENSHIP ~~SWEDEN~~
	POST OFFICE ADDRESS	POST OFFICE ADDRESS	CITY	STATE & ZIP CODE/COUNTRY

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

SIGNATURE OF INVENTOR 201	SIGNATURE OF INVENTOR 202	SIGNATURE OF INVENTOR 203
Heinrich Jürgensen		
DATE 25. April 2001	DATE	DATE

United States Patent & Trademark Office

Office of Initial Patent Examination -- Scanning Division

SCANNED, # 24

Application deficiencies found during scanning:

☒ Page(s) 30 of DRawings were not present for scanning.
(Document title)

☐ Page(s) ________ of ________________ were not present for scanning.
(Document title)

☐ ***Scanned copy is best available.***